CHARACTERIZING ELECTRICAL OUTPUT OF SANYO HIT 195 BIFACIAL PHOTOVOLTAIC MODULES BY ALTERING REFLECTIVE MATERIAL BELOW THE LOWER FACE ABSORPTIVE CELLS

A Thesis
by
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ABSTRACT

CHARACTERIZING ELECTRICAL OUTPUT OF SANYO HIT 195 DOUBLE BIFACIAL PHOTOVOLTAIC MODULES BY ALTERING REFLECTIVE MATERIAL BELOW THE LOWER FACE ABSORPTIVE CELLS

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Bifacial photovoltaic (PV) modules offer potentially enhanced power output over conventional modules due to their reported ability to harvest reflected radiation, increasing output up to an additional 30%. However, this enhancement has yet to be confirmed in the literature. Bifacial modules are comprised of a single crystalline layer enveloped by amorphous silicon thin film layers on both surfaces of the cell, allowing absorption from both upper and lower faces.

Reflectivity and geometry of the backing surface, presumably, will contribute to module output. Various reflecting materials and a roofing surface with a range of array angles potentially regulate the degree of concentrated radiation the arrays will absorb. Additionally, purposeful provisions to the reflective roofing surfaces may enhance the ability of the modules to perform to their maximum specifications.

I report on a study comparing the power output of two nominally identical 700 watt photovoltaic arrays utilizing equivalent system components and data logging equipment with varying configurations of reflecting geometries and materials. This study was undertaken at the Appalachian State University Solar Research Laboratory in Boone, NC, which houses two Class 1 pyranometers and pyrheliometer. PV power was reported under well-quantified irradiance conditions, including direct beam fraction.

Six trials over six months (November-April) with varying reflective materials and geometries revealed that different reflecting materials did not significantly change power output. Mounting an array at 0˚ did adversely affect power output compared to the array at a 36˚ angle relative to horizontal using the same reflective material. Additional studies with varied materials and geometries different from those tested may improve the power output. The arrays may have performed differently during summer months when the sun angle is higher.

DEDICATION

I would like to dedicate this thesis to my wife Nancy, who continued to balance family activities and a career in the medical profession while I attended Graduate School. This dedication also extends to my daughter Aubrey and my son Tanner, who both were very supportive throughout my many long hours of graduate research, and to my mother, Giuseppina Angeline Sciara, who at 87 years of age keeps me laughing.

ACKNOWLEDGMENTS

I would like to thank Sanyo Corporation (Panasonic) for donating the bifacial modules used in this study, DuROCK ALFACING INTERNATIONAL Manufacturing Company for providing TIOCOAT™, Boone Paint for supplying Benjamin Moore® Waterproof Aluminum Paint, SWARCO glass beads, and canvas. Additionally, I would also like to thank the Department of Technology and Environmental Design for supplying connectivity supplies, and the Appalachian State University Renewable Energy Initiative (REI) for its support and for providing space and additional equipment that was crucial to the completion of the project. I would like to thank my fellow colleagues for assistance in installing the modules at the Solar Laboratory.

This thesis would not have been possible without the assistance of my Thesis Committee-Dr. Brian Raichle, Chairperson, Dr. Margot Olson and Dr. Dennis Scanlin. Special thanks to Dr. Marie Hoepfl who spent untold hours teaching Graduate Students the science of research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

The recent introduction of Sanyo Heterojunction with Intrinsic Thin Layer (HIT) 195 Double Bifacial Photovoltaic (PV) Modules to the retail market suggests the need to investigate types of locations in which they may be installed in order to obtain the best performance possible based on their unique design. The HIT Double Modules utilize the upper and lower faces of the module to generate electrical power. According to the manufacturer, a wattage increase of up to 30% may be realized by properly installing the modules in locations where light may reach the lower face of the module ("Sanyo HIT Products," 2010). The additional power produced is determined by module orientation relative to a reflecting surface, geographic location, installation techniques, shadows produced by the grid system holding the modules, weather, and reflective properties of the varied surfaces below the modules.

Using eight Sanyo HIT 195 Double Bifacial Modules, the study was designed to characterize power output by altering the reflectivity of the lower surface material in a non-traditional array and angle. As a result of this research, optimal materials may be identified or developed for use on lower reflective surfaces in a bifacial module canopy as well as other installations. The use of a UNIRAC SOLARMOUNT (Unirac, 2012) rack system will suspend the modules off the roof surface to permit an exchange of reflective materials below the modules.

Statement of the Problem

Sanyo Corporation manufactures bifacial photovoltaic modules that have light absorptive cells on both upper and lower surfaces. Technical specifications indicate each module may produce additional power of up to 30% by utilizing the back of the module. A range of installations will net varying electrical outputs due to the reflective area variations below and around the modules.

The study will assess the output of the HIT 195 Double Module when various materials are placed below the modules along with different geometries. Flat rooftop installations would provide additional options over canopy installations, but use of varying materials and geometries at a testing facility will help determine which reflecting surface or geometry may improve power output.

Limited independent research has been conducted to verify the performance of bifacial PV modules have potentially limited adoption of this product, as well as inconsistencies in estimated increases in power output. A systematic study of the type and geometry of reflecting surfaces, as well as module performance may promote implementation of bifacial modules to a greater extent.

Purpose of the Study

This study provided a comparison of power output of two arrays consisting of Sanyo Bifacial Modules. The testing of reflective materials as well as a change in geometry of the modules will help characterize electrical output. Conversion efficiency for commercial PV modules in field installations generally ranges from 13% to 17% ("The photovoltaic cell," 2012). The Sanyo HIT 195 Bifacial Module has a cell efficiency of 19.3%, but by testing these modules with varying geometries and reflective materials, it may be possible to increase their efficiency and verify Sanyo’s claims of performance.

Research Questions

It is important to state that all PV modules will perform conditionally on their placement, installation, geographic location, and their upkeep (such as cleaning the glass surfaces as needed).

I proposed two questions that initiated this research:

1. Will the use of various materials below the arrays of Sanyo HIT 195 Double Bifacial Modules affect electrical output?

2. Will varied geometry of the array of Sanyo HIT 195 Double Bifacial Modules affect electrical output?

With the data collected over the course of the study, a determination may be made to either support Sanyo Electric Corporation's claim of a possible increase in power up to 30%, or not support the claim. Altering the reflective materials below the series of modules will enhance the study.

Definition of Terms

AC: Alternating current.

BIFACIAL: Consisting of two sides, specifically upper and lower surfaces of a module.

DATA LOGGER: An electronic device that records a series of measurements over time.

DC: Direct current.

DIRECT RADIATION: Radiation that reaches the Earth's surface without scattering.

DIFFUSE RADIATION: Radiation that is scattered by the atmosphere and clouds.

DNI: Direct normal irradiance.

GLOBAL RADIATION: Both direct and diffuse radiation.

HIT: Heterojunction with Intrinsic Thin Layer.

INVERTER: An electronic devise that converts direct current (DC) in to alternating current (AC).

PDIFF: Power difference.

POA-PLANE OF APERTURE IRRADIANCE (ARRAY): Irradiance that falls on a plane that is parallel to the array.

POWER: Measured in watts.

PV: Photovoltaic.

PYRANOMETER: Measures total global solar irradiance from the whole sky.

PYRHELIOMETER: Measures direct component of solar irradiance from the sun (mounted on tracker).

REFLECTANCE: Reflected radiation from a point of incidence on a surface.

SOLAR IRRADIANCE: Power of solar radiation per unit area expressed in watts per meter squared (W/m2).

TRANSDUCER: An electronic device that receives a signal in one form of energy and transmits it to another signal form.

W: Watts.

Limitations of the Study

This study was conducted in Boone, NC at the Appalachian State University Solar Lab with coordinates of latitude 36˚12’24.53”N, longitude 81˚39’18.79”W. While using one location for a study is not optimal, results may be suggested for other locations by use of National Renewable Energy Laboratory (NREL) data. While many other PV modules were on the market at the time of this study, only Sanyo HIT 195 Bifacial Modules were used. Two series of three modules each were configured. Since the lower portion of the bifacial module is light absorptive, control series of modules were tested with standard asphalt shingles. Using one inverter for three modules created an additional challenge. If a portion of one module surface becomes blocked or shaded, performance of the complete series of three modules may be reduced. Shading will always inhibit direct irradiance absorbance and will reduce the output of modules as well as the arrays to which they are wired. While shading can be difficult to avoid, every attempt was made to keep shading to a minimum. As the position of the sun changes over time, the location of the shadows on the reflective surfaces created by the module mounts will also change.

Significance of the Study

The results of the study may be useful to the manufacturer by enhancing the marketability of bifacial photovoltaic modules for many different rooftop applications where a canopy or facade may not be available or practical. The study may benefit the end user since the bifacial modules may be installed on a pitched rooftop of a residence or business. This study also provided an independent examination of performance as it relates to the manufacturer’s specifications.

Additionally, a recorded power increase may serve as useful data to Appalachian State University, Department of Technology and Environmental Design, and the Sanyo Electric Corporation, as well as help modify future installations to net the highest power output of these modules.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Structure and Functionality of Sanyo HIT Bifacial PV Modules

PV cell performance continues to improve with technology. The cells are currently capable of maintaining approximately a 17% efficiency level ("The photovoltaic cell," 2012). Depending on the manufacturer, the type and quality of the cell, and its age, this percentage may increase or decrease. Most cells are tested in a laboratory where certain conditions are constant, permitting the manufacturer to make claims about their performance. The Sanyo HIT 195 Double Bifacial Modules have a cell efficiency of 19.3% in a laboratory setting ("HIT Double 195 Spec. Sheet," 2010), but this percentage varies depending on their location and installation.

The Sanyo HIT 195 Double Bifacial Photovoltaic Module attempts to produce higher power output per area by use of both top and bottom surfaces of the module. The modules may be installed at nearly any angle, but similar positioning to other PV modules would be most effective in an application with solar tracking and a lower opposing surface white in color or some other type of reflective material. The modules are designed to allow a small percentage of light transmittance to assist with lower module surface absorption and to create an aesthetically pleasing detail for canopy installations. The area below the module remains partially illuminated by light transmittance through the clear glass to assist in producing power ("Sanyo HIT Products," 2010), but the majority of the light is absorbed by the upper cells where most of the power is generated.

Traditionally, PV module performance is reported under Standard Test Conditions (STC) (Irradiance (I) =1000W/m^2, Temp=25˚C), but STC do not factor in nearby reflecting surfaces or their orientation. For purposes of clarity, STC are defined as: The most common and internationally accepted set of reference conditions, and rates module performance at a solar irradiance of 1000 W/m^2, spectral conditions of AM1.5, and a cell temperature of 25°C or 77°F (Dunlop, 2010).

Therefore, bifacial manufacturers report front-side performance only under STC in laboratory conditions, and additionally report a range of possible power enhancements produced under certain circumstances. This accounts for the HIT 195 Double Module rating of 195 watts, but an additional 30%, or a maximum of 54 additional watts, may be produced by the lower cell surface for a total output of 249 watts per module ("HIT Double 195 Spec. Sheet," 2010).

The main element used for a solar module semiconductor is silicon. N-type (free electrons) silicon has had phosphorous added to it while a p-type (electron voids) silicon has had boron added ("Solar Power (Solar Cells) The Components of a Solar Cell", 2011). A conventional solar cell consists of minimal layers: an electrode, glass with an anti-reflective layer, n-type, p-type, crystalline Si, and a metal electrode (Figure 1).

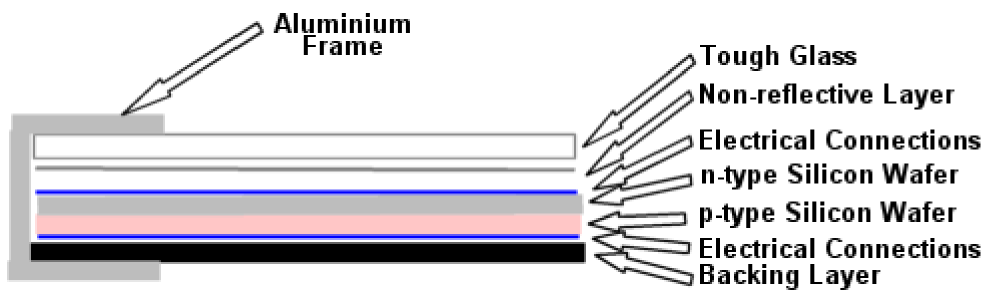

Figure 1. Conventional solar cell (Solar-fact.com, 2012).

Sanyo HIT 195 Bifacial Modules combine the use of single crystalline silicon (Si) with extremely thin amorphous silicon layers (a-Si) on both sides of the cell to allow both the front and back side of the photovoltaic module to absorb light and produce energy. Heterojunction with Intrinsic Thin Layer (HIT) modules have high conversion efficiency, excellent temperature characteristics, and a considerable output under diffuse and low light conditions ("Sanyo HIT Products," 2010).

By contrast, the HIT Double Module has many layers: a top electrode, p-type amorphous Si, intrinsic amorphous Si, crystalline Si (n-type), another layer of intrinsic amorphous Si, intrinsic amorphous Si, n-type amorphous Si, and a bottom electrode. This multi-layering effect allows light absorption from both sides. Compared with conventional solar cells, HIT solar cells (Figure 2) have a better temperature coefficient and a higher-open circuit voltage (Zhao, Zhou, Li, Diao, & Wang, 2008).

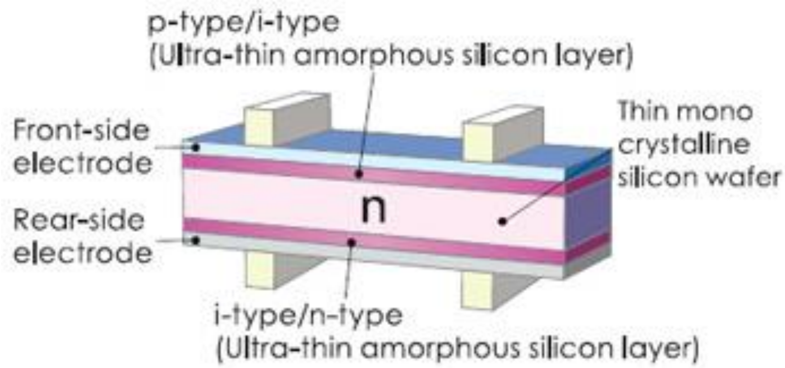

Figure 2. Sanyo HIT solar cell (Sanyo HIT Products, 2010).

In a recent press release, “SANYO North America Corporation (SANYO), a subsidiary of SANYO Electric Co., Ltd., announces that as of April 1, 2012, the branding of its HIT® solar modules, will change from ‘SANYO’ to ‘Panasonic’,” (Fowles, 2012).

Power vs. Size of HIT Modules

Bifacial modules are designed for optimal performance with minimal space and are available in different power outputs, depending on the application. A Sanyo HIT 215 Monofacial Module physically, is 13.53 square feet with an STC rating of 215 watts, compared to a Sanyo HIT 195 Double Bifacial Module at 12.8 square feet, with an STC of 195 watts per module. For the bifacial module, the lower face cells may facilitate an increase in power to 249 watts in less area than the monofacial modules ("HIT Double 195 Spec. Sheet," 2010). By calculating the power output of a series of ten modules, Sanyo Bifacial modules would consume 7.3 fewer square feet than Sanyo Monofacial modules, but at Bifacial maximum rated efficiency, may possibly produce an additional 340 watts.

System Components

Eight Sanyo HIT 195 Bifacial modules were used in different configurations and geometries along with three different reflective materials. Two series of modules were installed so that two separate systems would operate independently of each other by design.

Two Ohio Semitronics PC8-004-08X5 transducers sent power data each minute from their respective bifacial arrays to a Campbell Scientific Data Logger.

An SMA SUNNY BOY US-700 inverter on each system converted the electricity generated from direct current (DC) into alternating current (AC) (SMA America LLC, 2012). The inverter was wired to a power box for the system to be grid tied. An inverter should be used that has a higher maximum output power than the array of modules. For example, a series of 10 standard monofacial HIT 220 modules would need an inverter rated for 2200 watts. In the case of the HIT 195 Double Modules, the *potential* power for both upper and lower sides for a series of 10 would be 2490 watts (249 watts x10 modules); where 249 would theoretically be the maximum power output for both upper and lower surfaces of one module. An inverter capable of handling nearly 2500 watts would need to be used for an array of 10 modules.

Module Life Expectancy and Poor Performance

Sanyo Energy Corporation warrants the HIT 195 Double Modules for two years' workmanship and 20 years' power output. With any solar module, efficiency decreases with the layering of dust or dirt on the face of the module. Bifacial modules in a horizontal installation may collect more debris since they would be slightly harder to clean and rain will not remove as much debris as if the module were in an angled application. A benefit to the bifacial module is that it still absorbs light from below, and the underside of the module is not as likely to receive as much debris due to weather exposure.

Experimental Applications of Bifacial Modules

Although research on bifacial photovoltaic modules began in the early 1960s, Sanyo Electric Co., Ltd. developed and trademarked the HIT Double Modules in 2010 ("Sanyo HIT Products," 2010). Their primary use has been in canopies and solar screening applications to capture energy and to help reduce solar gain indoors in the summer. They may also be installed in ballast mounts or on vertical walls.

An experimental study done in Madrid, Spain in 1984 with bifacial photovoltaic modules found that they collected 59% more energy than monofacial modules when utilizing a white painted floor (Luque, Lorenzo, Sala, & Lopezromero, 1985). Many years prior in other experimental studies, findings revealed that "the increase in power conversion density that is achievable by using bifacial solar cells depends on the conversion efficiency of the cells under back illumination, which can be as high as 94% of the front efficiency, and on the amount of light that reaches the back surface" (Cuevas, Luque, Eguren, & Delalamo, 1982, p. 420).

As of 2005, The European Photovoltaics Industrial Association determined that flat-panel crystalline silicon modules comprised 90% of photovoltaic devices produced. The Association estimated that cell efficiency would need to increase from 12% to 20% utilizing contacts on the back surface, regarded as back contact solar cell (BCSC), in an attempt to develop high-efficiency contacts. In addition to this modification, it was noted that development of bifacial cells with BCSC could drive down the cost of per peak watt (W_P). This study, conducted with the use of a laminated grid of wire external busbars (LGWEB), in combination with bifacial Czochralski-grown silicon (Cz-Si), recommended this type of module could potentially produce an increase in efficiency exceeding 21% (Untila et al., 2005). The development of high-efficiency contacts on the back surface of the cell would reduce the amount of silicon used and reduce the production costs. In contrast, *Development Status of High-Efficiency HIT Solar Cells*, a study recently completed, specifically noted that the Sanyo HIT Double Module is capable of producing 10.9% more output than a single upper side HIT module (Mishima, Taguchi, Sakata, & Maruyama, 2011) .

A hybrid solar thermal system using bifacial modules was tested using a transparent solar plane in the working spectral region of a PV module. A determination was made that a bifacial PV module could be used for solar thermal and that the bifacial module produced approximately 40% more electrical energy than the conventional PV modules (Robles-Ocampo et al., 2007).

Two case studies highlighted by Sanyo include the successful home, lumenHaus, built by Virginia Tech that won the Solar Decathlon 2010 in Europe, and a solar canopy installation on an office building in Atlanta. What is not stated in either of the two case studies is what material was used below the modules for the lumenHaus or for the surface below the canopy of the Atlanta office building (Fowles, 2010). DuROCK Alfacing International Manufacturing Company in Woodbridge, Ontario has mounted a 10 kilowatt array of HIT 195 Double Modules at a 30° angle on their flat roof (Figure 3). The reflective material used below the modules was TIOCOAT™, a white protective roofing material. The bifacial modules as reported produced between 195 watts and 210 watts (SolarTown, 2011). In October of 2011, I visited DuROCK and met with Jonathan Ursini, the company's business manager, who conducted a roof tour of his facility (Figure 4), Canada's first solar rooftop installation using Sanyo HIT Bifacial Modules and TIOCOAT™, a product produced by DuROCK.

Figure 3. Photo of PV installation at DuROCK Alfacing International Manufacturing (Solartown, 2011).

Figure 4. Photo of Jonathan Ursini, Business Manager at DuROCK adjacent to information poster describing Canada's first Sanyo's first commercial bifacial installation.

Data were rather inconsistent, with few studies conducted to investigate the performance of bifacial modules. Sanyo Electric Corporation states that the HIT Double Modules are capable of producing power within their specifications (Appendix A). Each application and location will have a different effect on the module or series of modules.

The Institute for Solar Energy Research Hameln/Emmerthal (Institut für Solarenergieforschung Hameln, ISFH) tested a white surface behind bifacial modules. The Institute used the modules to shape the company acronym on the front of the building. Behind the bifacial modules, a white background was placed, capable of reflecting light onto the back surface of the module. The modules used were back-contacted bifacial solar cells (BACK OECO) produced experimentally by ISFH. The power output per cell was expected to be equivalent to that of at least a 30% efficient monofacial cell of the same size (Hezel, 2003).

Common Installation of Bifacial Photovoltaic Modules

The most common installation of Sanyo Bifacial Modules is in the form of canopies (Figure 5) that serve as covered walkways, carports, or porch roofs. Some applications use HIT Double

Bifacial Modules for window screens (when angled appropriately), skylights, and in other atypical roof installations with reflective material below.

The manufacturer recommends the following possible applications: architectural applications, awnings, balconies, bus shelters, Building Integrated Photovoltaic (BIPV) arrays (Dunlop, 2010), deck and porch coverings, canopies (Figure 5), carports, facades, fences, siding, trellises or tracking systems ("Sanyo HIT Products," 2010).

The flexibility of applications introduces new options that permit HIT 195 Double Module integration into net energy producing architectural details not previously realized. In other installations, modules were placed in angled ballasted frames on flat rooftops with light or white roofing material below the lower surface (Solartown, 2011).

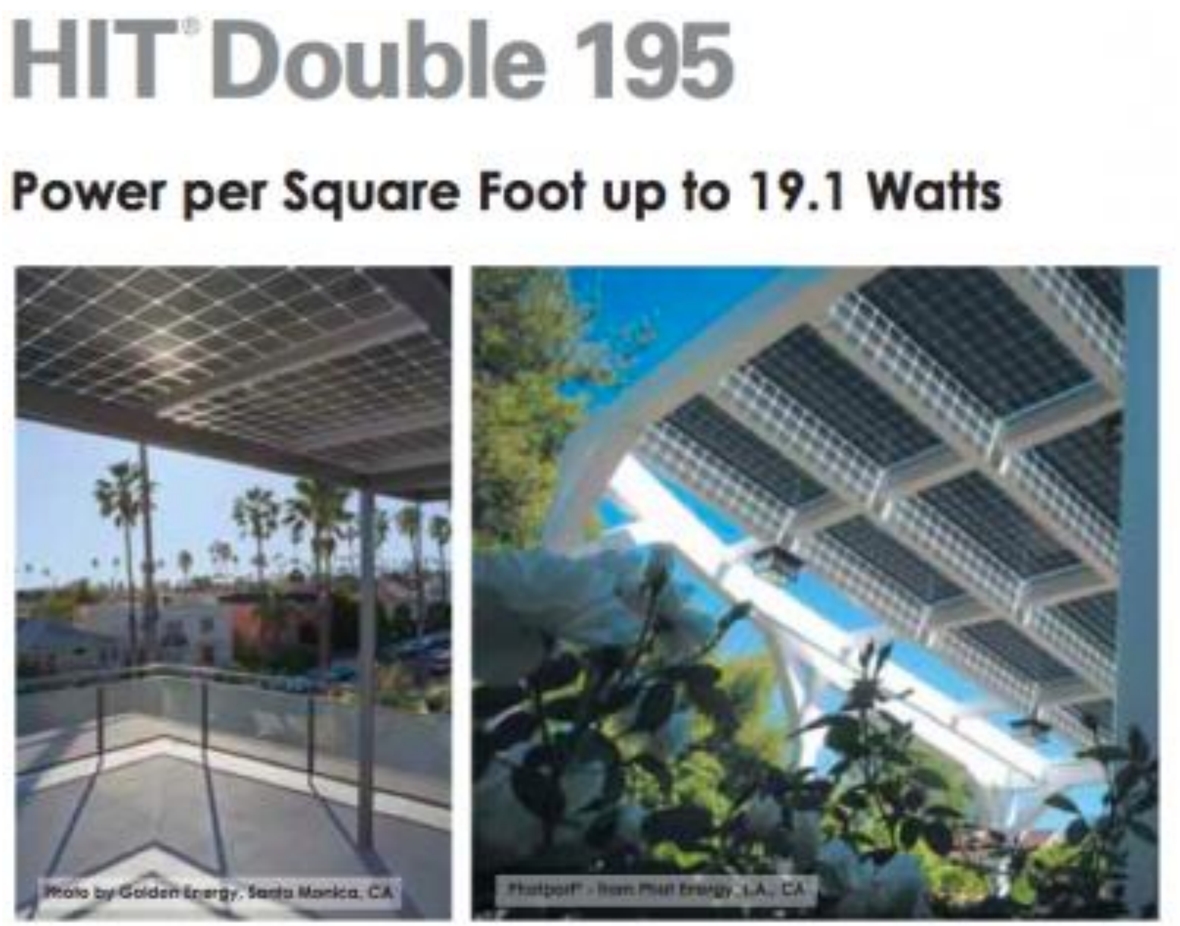

Figure 5. Photos of Canopy installations using Sanyo HIT Double Bifacial Modules (Sanyo HIT Products, 2010).

Designers and architects seem to favor the aesthetic appearance of the HIT Bifacial Modules. The traditional monofacial modules are commonly installed on a roof, either flat or pitched. Bifacial modules may become a functioning portion of the architecture as well as an electric generating device by integrating them in interesting structures purposefully designed to withstand the weight and wind shear.

CHAPTER 3: OVERVIEW OF THE RESEARCH DESIGN

Research Methods

The experimental design consisted of two nominally identical systems, each comprised of three Sanyo HIT 195 Double Bifacial Modules, a SMA Sunny Boy 700-US grid interactive inverter, and an Ohio Semitronics PC8-004-08X5 power transducers. The independent variable was the type of reflective material, and the dependent variable, power, was recorded each minute during all the trials. Two research grade pyranometers measured total global solar irradiance and a pyrheliometer measured the direct component of solar irradiance from the sun. Two Ohio Semitronics PC8-004-08X5 transducers supplied the Campbell Scientific data logger to record results.

Two arrays were mounted horizontally in a series with a positive terminal on the left of the array, and a negative terminal on the right. The two arrays were placed horizontally, one above the other, by use of UNIRAC aluminum racking (Unirac, 2012). In Trial 1 the upper array consisted of five modules employing the middle three wired in series, but the first and fifth modules on either end were not wired. The lower array consisted of three modules wired in series. The adjustable aluminum racking fastened to the mock roof held the modules parallel to the roof's surface in all trials but Trial 3 where a specially constructed frame permitted the horizontal placement of the lower array.

Methodology

The research was conducted on at the Solar Research Laboratory, Appalachian State University in Boone, NC (Figure 6). The Sanyo HIT 195 Double Bifacial Photovoltaic Modules were placed on a 36° angle mock roof. Two three-module strings were mounted using an aluminum frame. Each adjustable aluminum frame was parallel to the reflective roof surface. The net result was an array tilt angle of 36° relative to horizontal. In one trial, the lower array was configured horizontally (Figure 7).

The modules were fastened to the aluminum frame at a distance of 6 inches from the roof surface. Each array functioned independently of one another, and had identical electrical components and wiring. Additionally, 12-2 with ground wiring from the inverter to the breaker panel was cut to the same length for both systems. Both arrays were mounted on the UNIRAC rail system with clips acquired from UNIRAC specifically used for these Sanyo modules.

Figure 6. Appalachian State University Solar Testing Facility, Boone, NC. Arrow indicates location of module placement.

At the top and the bottom of one module series string, approximately 8 inches of reflective material was extended beyond the aluminum framework. The reflective materials used on the roof surface were sized 69 inches high and 180 inches wide, which allowed an additional 40.5 inches of reflective material on the far left of the left array and 40.5 inches on the far right of the right array, and assisted in capturing the maximum reflectance as the sun rose and set. Additionally, there were 19.5 inches between the upper array and the lower array.

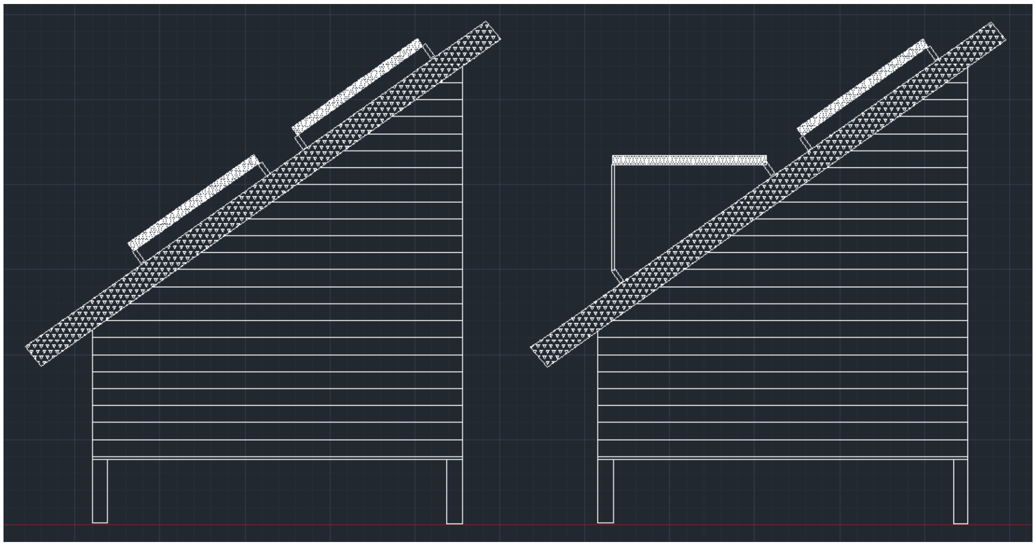

Figure 7. CAD model of side view of installation setup, racking, and solar modules illustrating the two different geometries used in this study. Roof angle 36° and modules 36° relative to horizontal, second illustration is roof angle at 36° with lower array a 0° relative to horizontal.

Initially, the upper array consisted of five modules with the three in the center wired together in series. The two outer modules were not wired to assist in determining if the shadows created on the sides of the three modules affected power output. The lower array consisted of three modules, all of which were connected (Figure 8).

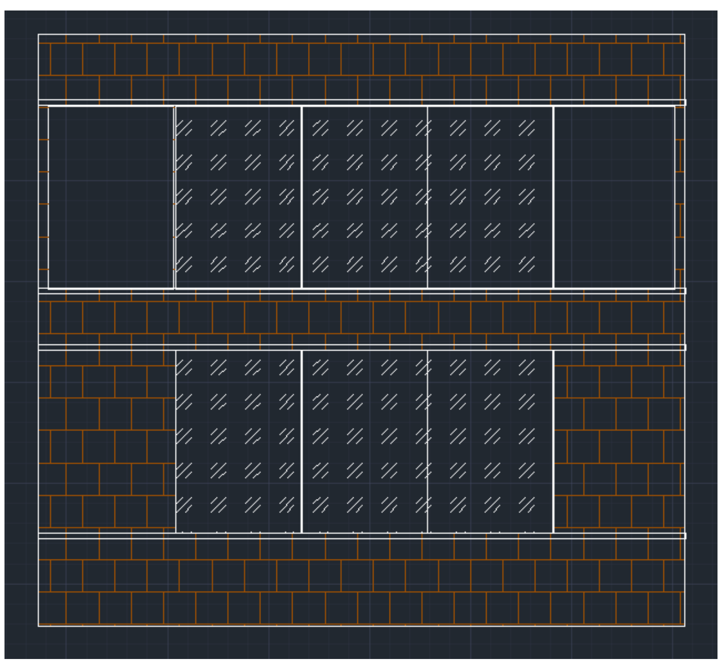

Figure 8. CAD Model of module layout. Upper and lower array wired. Upper array with nonfunctioning module on either side.

A different reflective material was placed on the roof surface directly below each series of three modules to help determine if reflectivity of one material produces a higher PV power output than another. Trials of three materials in different configurations were performed for a total of six sets of data. The modules were connected in two sets of three series using two Sunny Boy 700-US inverters. The Sanyo HIT 195 Double Bifacial Modules are manufacturer rated using STC at 195 watts with the potential of 249 watts at maximum output. At maximum output, the inverter tied to three of these modules should be able to support 747 watts. A technician from SMA America, LLC specified the SB 700-US stating this inverter has a power flex override of 3% for a total capability of 721 watts. The possibility of three modules producing an excess of 721 watts is negligible since conditions in Boone, NC would have to be nearly identical to the set of reference conditions as described above in STC. Conversely, the testing of reflective materials *could have* produced power at peak performance neighboring those specified by Sanyo Electric Corporation.

Installation of an aluminum rack for each series of modules, wiring, module mounts, inverters, transducers, and grid tying was completed prior to the commencement of data collection. With the use of a research grade pyranometer, the first set of data to be collected was direct radiation. Direct radiation is the solar radiation from the sun that reaches Earth's surface without scattering (Dunlop, 2010). Since most photovoltaic modules' electrical outputs are rated by the peak sun conditions (1000W/m^2), it is important to determine how may peak sun hours the module has received. Actual peak sun hours differ from calculated peak sun hours, because for the latter, early sun, peak sun, and late sun irradiance is averaged. While peak sun may be an hour or less, calculated peak sun may be equivalent to 4.8 peak sun hours (Dunlop, 2010). The pyranometer and Ohio Semitronics transducers collected data each minute and was recorded by the Campbell Scientific data logger.

The second set of data collected was diffuse radiation, solar radiation that is scattered by the atmosphere and clouds (Dunlop, 2010). A second Huksaflux pyranometer measured daily diffuse irradiation. The third set of data was the plane of aperture using a Huksaflux pyrheliometer, which is pointed directly at the sun to measure energy.

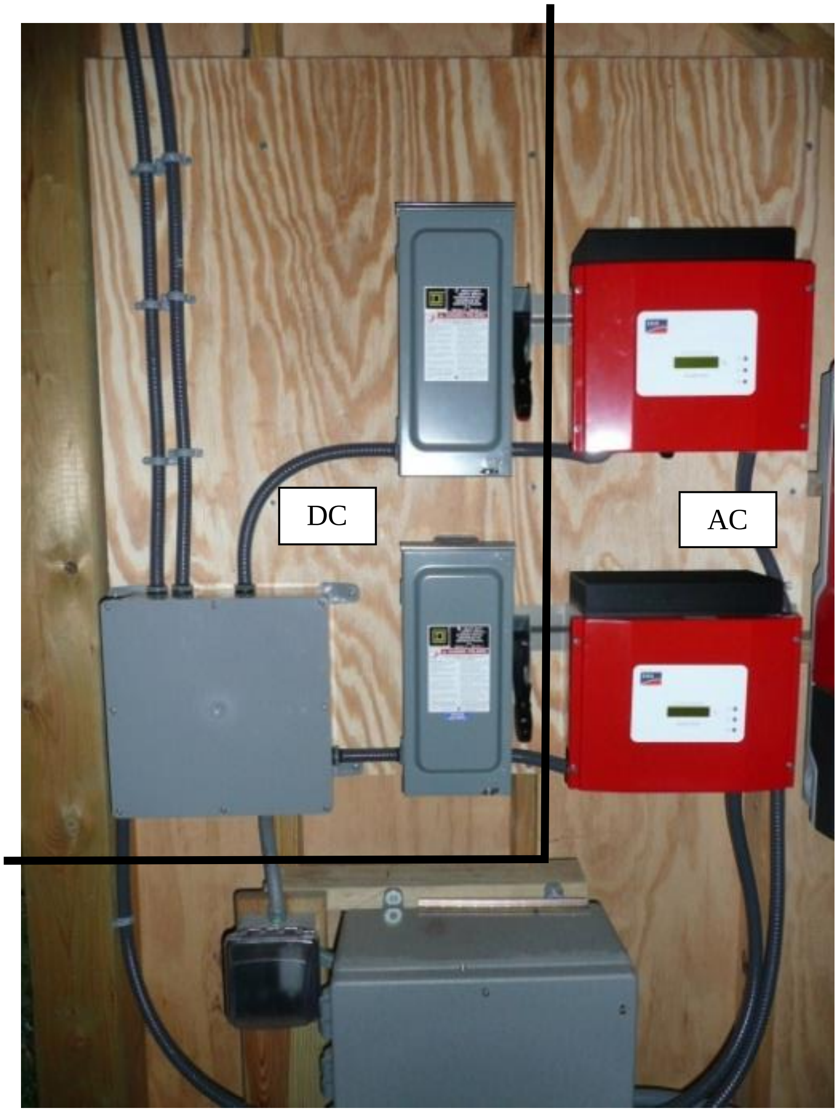

Figure 9. Photo of system electrical components with DC and AC indicators.

Data Compilation Sets

The following measurements were used during this study along with an analysis of each.

- Direct Radiation
- Diffuse Radiation
- Plane of Aperture total radiation
- Power outputs over trial periods recorded each minute

Major Components Necessary to Complete the Two Systems

The main components of equipment to perform this study included the following:

- Eight Sanyo HIT 195 Double Bifacial Modules
- Two SMA-America Sunny Boy SB-700US Inverters
- Two Ohio Semiconductor Transducers Model PC8-004-08X5
- Two Square D 600 Volt DC Disconnects
- Two Research Grade Huksaflux Pyranometers and Pyrheliometer
- Campbell Scientific CR100 Data Logger
- Three Reflective Materials

SMA-America, maker of the SUNNY BOY US-700 inverter, specifically states the wiring between the array and the inverter should be between #6 and #10. I used #10 wires placed in a ½-inch conduit as shown in Figure 9.

Wire sizing was determined by analyzing the system specifications and measuring the wiring run from the array to the inverter. The length of wire from the array to the inverter was less than 50 feet, and the short circuit current did not exceed five amperes. Between the inverter and the solar shed, I used #12-2 with ground. The system was grid tied inside of the shed.

Trial Configurations

By design, the duration of each trial was expected to be a minimum of 14 days, but all trials ran longer.

Table 1. Table of Trials.

TRIALS	ARRAY LOCATION	PERIOD OF TRIALS	QUANTITY	GEOMETRY OF MODULES	REFLETIVE MATERIAL
TRIAL 1	UPPER ARRAY	NOVEMBER 18-DECEMBER 2	FIVE-THREE WIRED	FLUSH MOUNT	MEDIUM BROWN SHINGLES
	LOWER ARRAY		THREE	FLUSH MOUNT	MEDIUM BROWN SHINGLES
TRIAL 2	UPPER ARRAY	DECEMBER 3-DECEMBER 31	FIVE-THREE WIRED	FLUSH MOUNT	WHITE TIOCOAT/SWARCO BEADS
	LOWER ARRAY		THREE	FLUSH MOUNT	WHITE TIOCOAT/SWARCO BEADS
TRIAL 3	UPPER ARRAY	JANUARY 1-JANUARY 31	THREE	FLUSH MOUNT	WHITE TIOCOAT/SWARCO BEADS
	LOWER ARRAY		THREE	HORIZONTAL MOUNT	WHITE TIOCOAT/SWARCO BEADS
TRIAL 4	UPPER ARRAY	JANUARY 30-FEBRUARY 22	THREE	FLUSH MOUNT	WHITE TIOCOAT/SWARCO BEADS
	LOWER ARRAY		THREE	FLUSH MOUNT	WHITE TIOCOAT/SWARCO BEADS
TRIAL 5	UPPER ARRAY	FEBRUARY 23-MARCH 9	THREE	FLUSH MOUNT	ALUMINUM PAINT
	LOWER ARRAY		THREE	FLUSH MOUNT	WHITE TIOCOAT/SWARCO BEADS
TRIAL 6	UPPER ARRAY	MARCH 29-APRIL 30	THREE	FLUSH MOUNT	ALUMINUM PAINT
	LOWER ARRAY		THREE	FLUSH MOUNT	MEDIUM BROWN SHINGLES

Trial 1

For Trial 1, a comparison was made with both the upper array and lower array operational using the asphalt shingles as the reflective material for gathering baseline data (Figure 10).

The premise behind the upper array design with two inactive modules was to determine if reflectance would enter from the left and the right sides. Since the lower array did not have blockage on either side, it offered the possibility to determine the extent of reflectance entering under the array from the sides. Data for this trial were collected over a 32-day period.

Objective: Determine if back side power production differs between edge shaded modules (upper array) and exposed edge modules (lower array).

Upper array:

- Mount: flush to roof with 6 inch spacing
- Surface: brown shingles
- Note: one unconnected panel on either side of the array

Lower array:

- Mount: flush to roof with 6 inch spacing
- Surface: brown shingles

The upper array had a non-functioning panel mounted on either side (five panels). Trial 1 data were collected between November 18, 2011 and December 2, 2011 (Figure 10).

Figure 10. Photo of Trial 1. Upper Array Shingle Flush 5 Modules, Lower Array Shingle Flush 3 Modules.

Trial 2

The second trial was the same physical configuration for the arrays in Figure 10, but a reflective roofing material was placed below the arrays to determine if this trial would net higher power output results.

Objective: Determine if roof coating effects back-side power production difference due to partial shading of edge shaded modules (upper array) and exposed edge modules (lower array).

Upper array:

- Mount: flush to roof with 6 inch spacing
- Surface: TIOCOAT™ with SWARCO glass beads
- Note: one unconnected panel on either side of the array

Lower array:

- Mount: flush to roof with 6 inch spacing
- Surface: TIOCOAT™ with SWARCO glass beads

The upper array had a non-functioning panel mounted on either side (total of five panels). Two coats of TIOCOAT™ (Figure 11) paint were applied to a heavy weight painter's cotton canvas tarp. SWARCO glass beads were cast onto the second application at a rate of 1.4 ounces per square foot of tarp before the last coat of TIOCOAT™ dried (Figure 12). The tarp was cut in half and placed under the two arrays. The tarp extended 8 inches beyond the top and bottom panel edges and 1 inch beyond the sides on the upper array. The lower array reflective material extended 8 inches above and below the array and 40 inches beyond the right and left panel edges on the lower array (Figure 13).

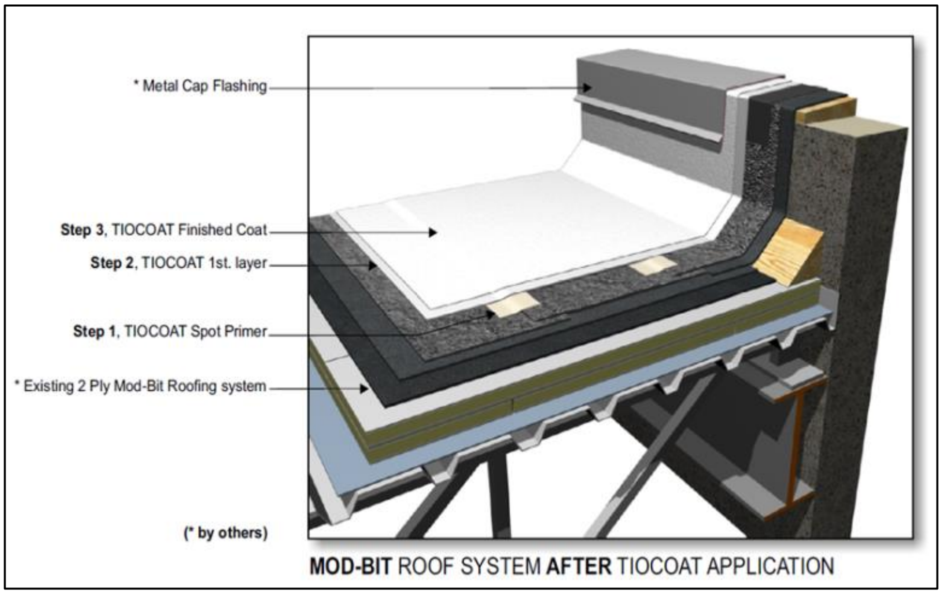

Figure 11. Diagram of TIOCOAT™ Reflective White Roof coating (TIOCOAT, 2011).

Figure 12. Photo of SWARCO glass beads used to enhance reflectivity in road striping (SWARCO, 2012).

Trial 2 data were collected between December 3, 2011 and December 31, 2011 (Figure 13).

Figure 13. Photo of Trial 2. Upper Array White TIOCOAT™ Flush 5 Modules, Lower Array White TIOCOAT™ Flush 3 Modules.

Trial 3

The third trial consisted of using the same reflective material in Trial 2, but the two outer unwired modules on the upper array were removed (Figure 14). Additionally, the lower array was tilted to achieve 0˚ or horizontal. Sanyo suggests this configuration in canopy installations. These data helped determine whether the tilt affects the absorption of diffuse radiation by the lower surface on the lower array.

Objective: Determine the effect on power output difference due to varying panel mounting orientation.

Upper array:

- Mount: flush to roof with 6 inch spacing
- Surface: TIOCOAT™ with SWARCO glass beads

Lower array:

- Mount: horizontal, with the bottom edge of the array elevated above the roof
- Surface: TIOCOAT™ with SWARCO glass beads

Trial 3 data were collected between January 1, 2012 and January 29, 2012 (Figure 14).

Figure 14. Photo of Trial 3. Lower array poised at horizontal. Upper Array White TIOCOAT™-3 Modules, Lower Array White TIOCOAT™ 3 Modules Horizontal.

Trial 4

Objective: Verify equal power outputs with identical experimental conditions (Figure 15).

Upper array:

- Mount: flush to roof with 6 inch spacing
- Surface: TIOCOAT™ with SWARCO glass beads

Lower array:

- Mount: flush to roof with 6 inch spacing
- Surface: TIOCOAT™ with SWARCO glass beads

Trial 4 data were collected between January 30, 2012 and February 22, 2012 (Figure 15).

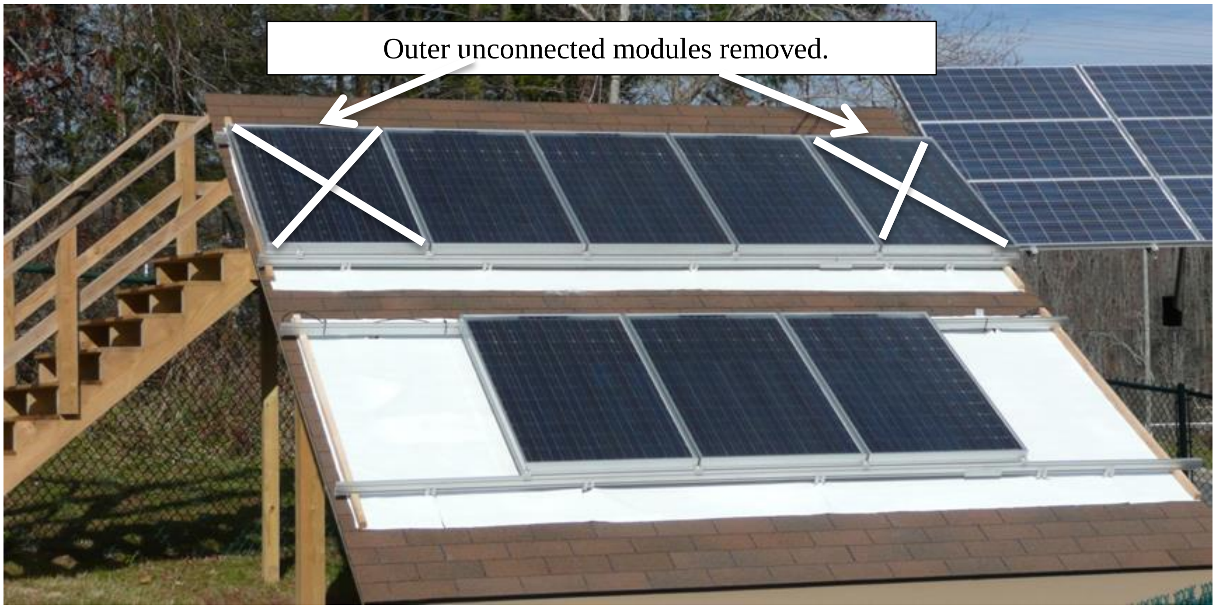

Figure 15. Photo of Trial 4. Upper Array White TIOCOAT™ Flush 3 Modules, Lower Array White TIOCOAT™ Flush 3 Modules

Trial 5

Objective: Determine the power output difference from differing reflective coatings below the arrays (Figure 16).

Upper array:

- Mount: flush to roof with 6 inch spacing
- Surface: Benjamin Moore Weatherproof Aluminum Paint

Lower array:

- Mount: flush to roof with 6 inch spacing
- Surface: TIOCOAT™ with SWARCO glass beads

Three coats of Benjamin Moore® Weatherproof Aluminum Paint were applied to a canvas tarp that covered the roof shingles. The tarp extended 8 inches beyond the top and bottom panel edges and 40 inches beyond the right and left panel edges. Trial 5 data were collected between February 23, 2012 and March 9, 2012 (Figure 16).


Figure 16. Photo of Trial 5. Upper Array Silver Roof Paint Flush 3 Modules, Lower Array White TIOCOAT™ Flush 3 Modules

Trial 6

Objective: Determine the power output difference from a reflective surface vs. a non-reflective surface below the arrays (Figure 17).

Upper array:

- Mount: flush to roof with 6 inch spacing
- Surface: Benjamin Moore Weatherproof Aluminum Paint

Lower array:

- Mount: flush to roof with 6 inch spacing
- Surface: medium brown asphalt shingles

Trial 6 data were collected between March 29, 2012 and April 30, 2012 (Figure 17).

Figure 17. Photo of Trial 6. Upper Array Silver Roof Paint Flush 3 Modules, Lower Array Shingles Flush 3 Modules.

Data Collection and Analysis Procedures

The electrical output of each series of modules, irradiance, horizontal diffuse irradiance and Plane of Aperture (POA) total irradiance were measured every minute over the course of each trial period. The trial durations were designed for a minimum of two weeks. Data was compiled and characterized by geometry and reflective material used to determine efficiency (either increased or decreased) of the modules. Data were also graphed for one day within the trial period to illustrated typical performance of the arrays. Binned data was analyzed to compare direct beam irradiance, diffuse beam irradiance, plane of aperture irradiance, and direct beam fraction to insure the climatic conditions were similar for each series.

The data were captured at one-minute intervals during each trial period using a Campbell Scientific CR1000 with Loggernet software. Excel spreadsheets of raw data (.txt) were converted to Excel 2010 .xlxs files and merged with weather files corresponding to the same minute. Nighttime data were excluded prior to data being analyzed. Initially, the period between 8:00 a.m. and 4:00 p.m. was reviewed over all six trials. It was determined that erratic data were present prior to 10:00 a.m.

and after 2:00 p.m. possibly due to shading of one or both of the arrays. A determination was made to use the timeframe of 10:00 a.m. to 2:00 p.m. since this period included un-shaded data closest to solar noon over all the trials.

CHAPTER 4: FINDINGS

Data were collected from November 17, 2011 through April 20, 2012. Minutes with power greater than 100 watts on both upper and lower arrays were analyzed. The wiring configuration of the two systems was such that power for both arrays was channeled to the power transducers and recorded prior to reaching the inverters. Non-zero power was observed at nighttime from each power transducer. Based on distributions of measured nighttime power, correction factors of -2.8 watts and +2.4 watts for the upper and lower arrays, respectively, were calculated to zero these readings, and applied to the measurements.

Trial 1

November 18-December 2

The Trial 1 data sample on a representative day, November 20, 2012 (Figure 18) indicates very little power difference with a nearly identical graph for both arrays. In this trial, both upper and lower arrays were flush mounted 6 inches over medium brown shingles, but the upper array had additional unconnected modules on both the left and the right sides. Lack of direct reflectance on the sides of the upper array had little effect on the power output compared to the lower array without the additional side modules. The power output for both arrays varied from 300 watts to 535 watts, with only slight variations between the two. One possible explanation of this variance is to conclude that the power differences were possibly caused by clouds shading both arrays.

As indicated in Figure 19, the distribution of percent power differences shows a rather normal distribution suggesting the addition of the two unconnected modules on either side of the upper array resulted in less than a 0.02% power output difference between the arrays. The average percent power difference was 0.017± 0.01% with N=2,869 (N being the number of minutes used in the trial). The data suggests that using the two additional modules to create purposeful shading on either side of the upper array caused little difference in power output.

The time ordered graph shown in Figure 20 shows that between the hours of 10 a.m. and 2 p.m., the lower array consistently performed better than the upper array throughout the day, but only by approximately .25%. Error bars generally indicate higher confidence intervals between -0.06% and -0.03% power difference. Lower confidence levels appear more often after 12:15 p.m. As seen in the graph of percent power difference vs. plane of aperture irradiance (Figure 21), at a low plane of aperture irradiance, the upper array outperforms the lower array. At a high plane of aperture irradiance, the lower array outperforms the upper array.

In summary, it is possible to conclude that the two unconnected modules on the upper array had little effect on power output, thus there were no substantial power differences between the two arrays during this trial.

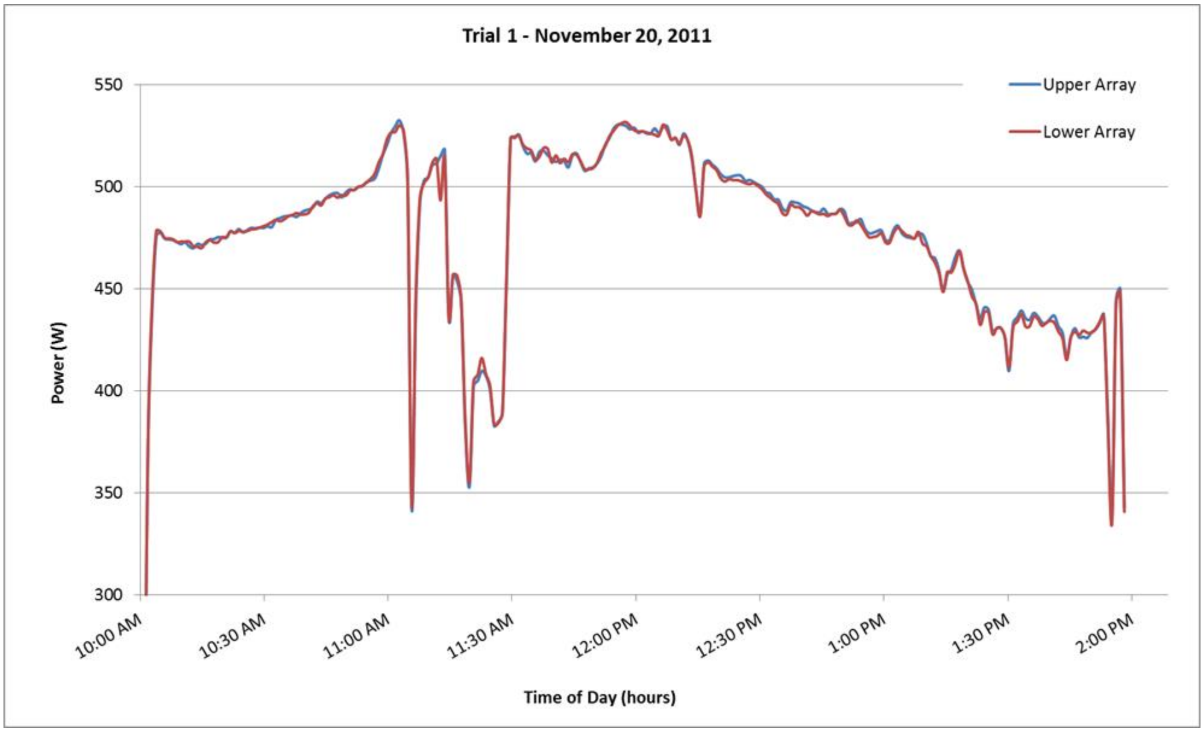

Figure 18. Chart of Trial 1. Power output on November 20, 2011. Shingle Roof with 5 Modules, Shingle Roof with 3 Modules.

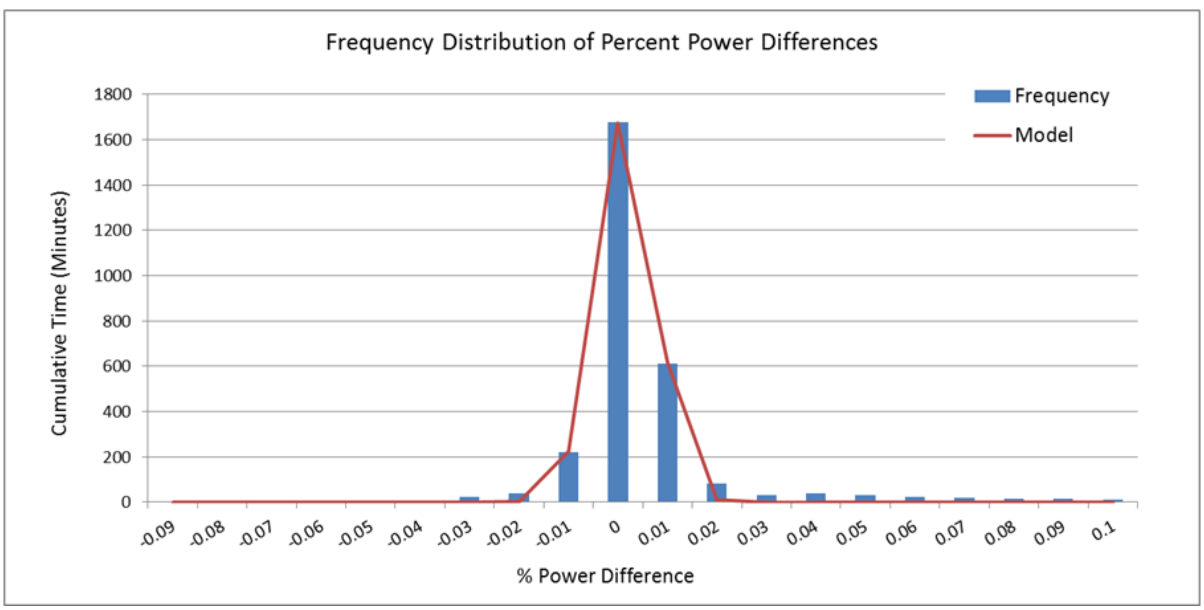

Figure 19. Chart of Trial 1. Frequency Distribution of Percent Power Differences

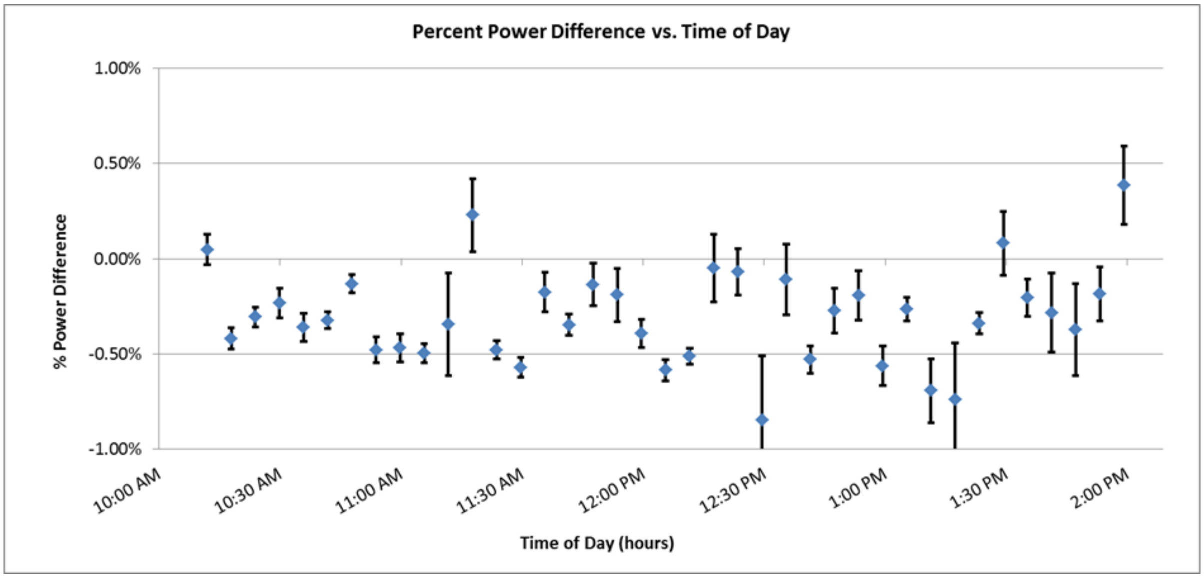

Figure 20. Chart of Trial 1. Percent Power Difference vs. Time Day.

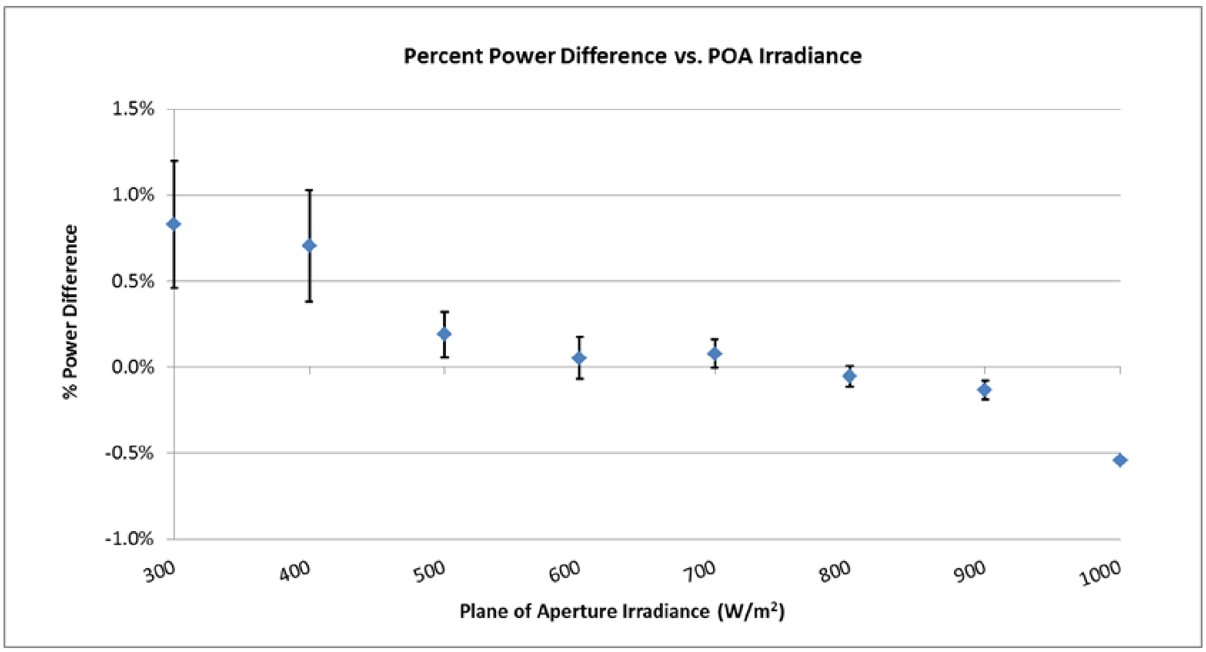

Figure 21. Chart of Trial 1. Percent Difference vs. POA Irradiance.

Trial 2

December 3-December 31

Both arrays were flush mounted 6” above the surface of a TIOCOAT™ and SWARCO glass bead configuration, with the upper array consisting of an inactive panel on either side of the upper array as in Trial 1. As an example, Trial 2 data for December 18, 2012 suggests that both the upper array and the lower array may have had some possible shading prior 10:30 a.m., and the lower array slightly outperformed the upper array between 10:30 a.m. and 2:00 p.m. (Figure 22). Power output for both arrays was rather consistent after 10:30 a.m., but the lower array noticeably outperformed the upper array.

The frequency distribution of percent power difference shown in Figure 23 represents a rather normal distribution with the lower array slightly outperforming the upper array. Average percent power difference was -0.61% ± 0.01% with N=6784. The error bars in Figure 24 show consistent smaller uncertainties after 1:00 p.m., unlike the greater uncertainties seen before 1:00 p.m. More specifically, the lower array outperformed the upper array before 11:00 a.m. and after 1:00 p.m. The greatest percent power difference vs. time of day approaches 4%, and occurred at 800W/m^2 as shown in Figure 25. Error bars indicate a lower confidence levels between 500W/m^2 and 800W/m^2 suggesting increased variation in each irradiance bin compared to Trial 1.

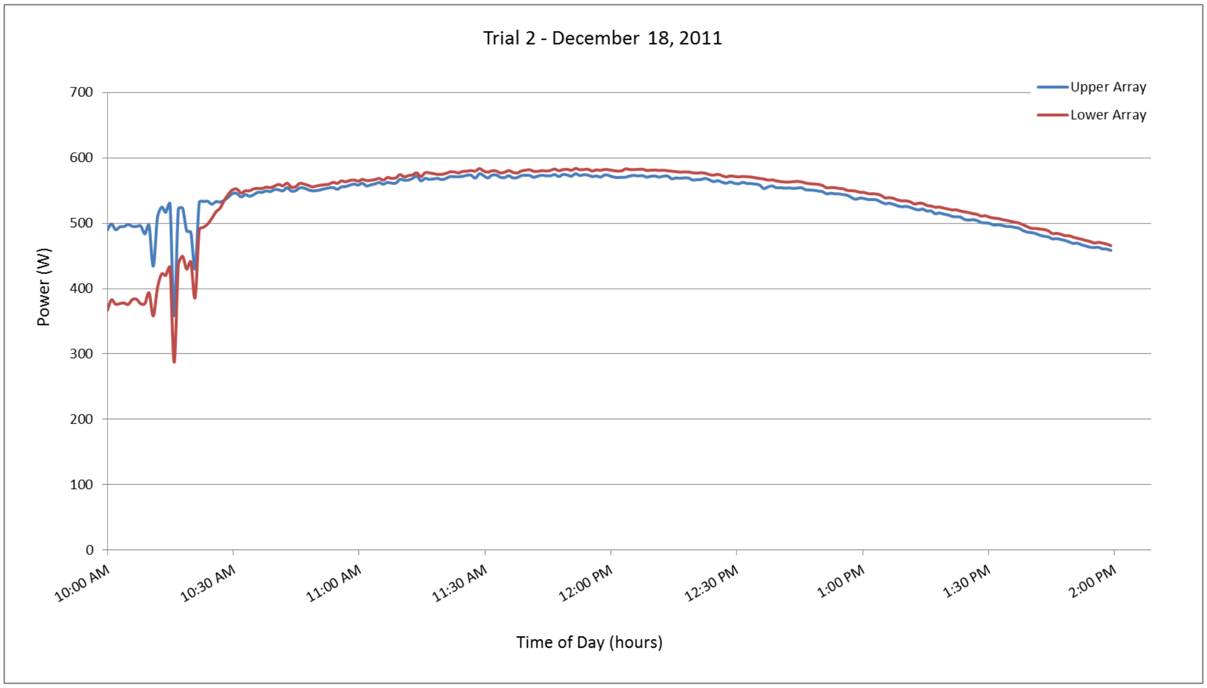

Figure 22. Chart of Trial 2. Power output on December 18, 2011. Upper Array White TIOCOAT™ 5 Modules (Two Outer Unconnected), Lower Array White TIOCOAT™ 3 Modules.

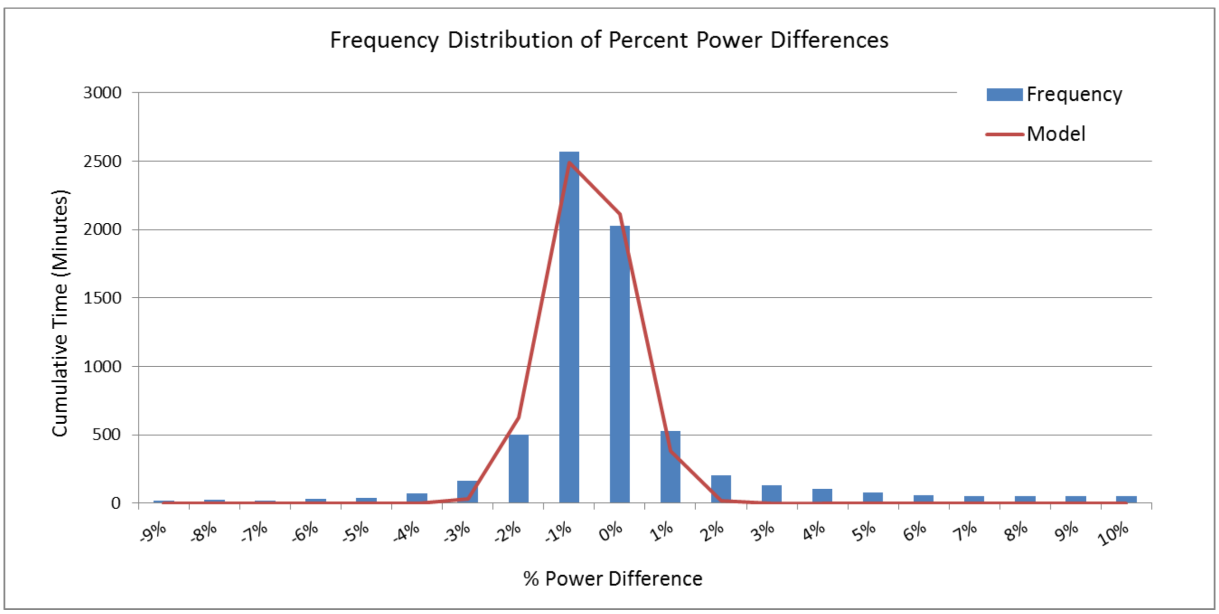

Figure 23. Chart of Trial 2. Frequency Distribution of Percent of Power Differences.

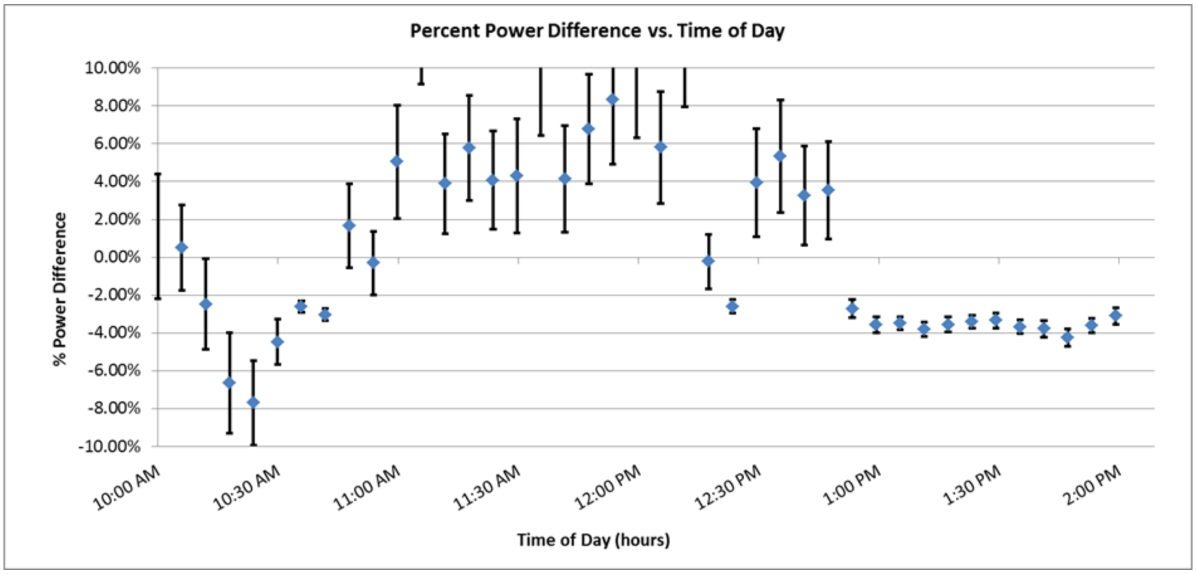

Figure 24. Chart of Trial 2. Percent Power Difference vs. Time of Day.

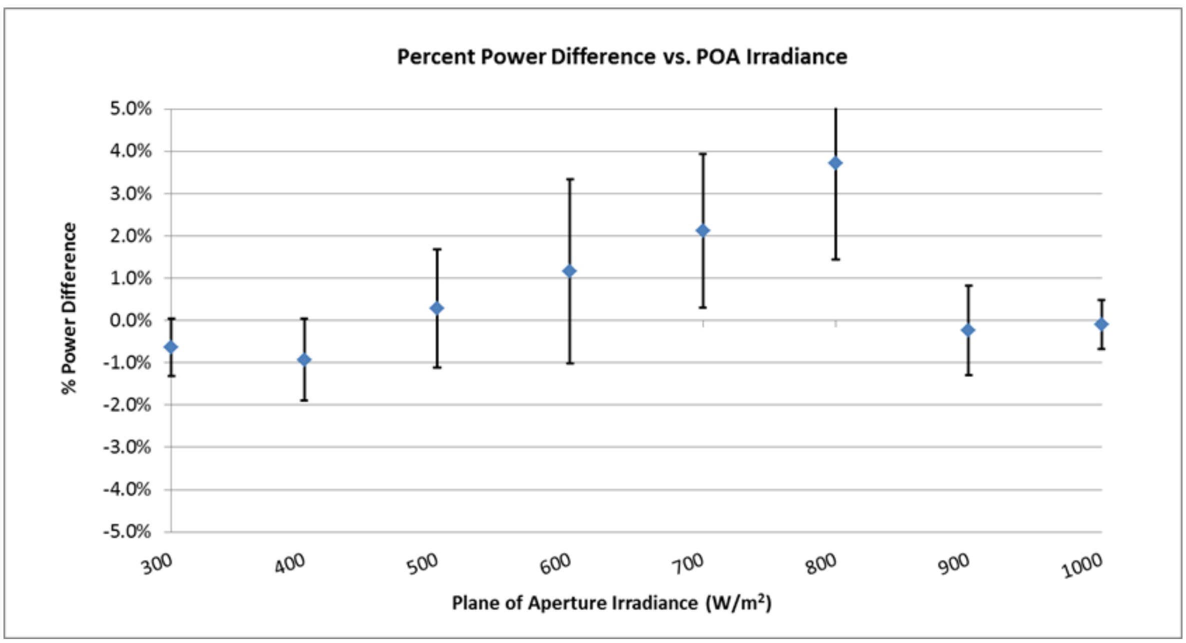

Figure 25. Chart of Trial 2. Percent Power Difference vs. POA Irradiance.

Trial 3

January 1-January 29

The configuration for Trial 3 used the same reflective TIOCOAT™ and SWARCO glass beads for both arrays, but the configuration of the upper array and the geometry of the lower array were modified. Both inactive modules (shading modules) from the upper array were removed leaving an array of three connected modules. The lower array was raised so the surface of the modules was poised at 0˚ or 36˚ relative to the reflective surface. Data in Figure 26 for January 14, 2012 suggest that the upper array performs similar to the previous trials, but the lower array power was drastically reduced, quite possibly from the change in tilt of the array. The decrease power output occurring from both arrays are indicative of possible heavy cloud cover for a brief period. This horizontal positioning, one suggested by Sanyo Corporation for use in overhead canopies, clearly limits the production of power, at least in this configuration, in this location, during this trial. It is noted that the geometry of the reflective material was at a 36˚ angle to the lower surface of the modules, which may or may not be typical.

Unlike the previous trials, the distribution in Figure 27 is a bimodal distribution suggesting two separate normal distributions, one in which the upper array *typically* outperforms the lower array. The upper array outperforms the lower array by means of occurrence, with the greatest power difference occurring between 35% and 40% power difference. The upper array has a consistently higher percentage of power difference during the trial over the four-hour period in comparison to the lower array, but tends to decrease after 1:00 p.m. (Figure 28) because of an increase in power of the lower array. There is not a normal distribution, but rather a strong variation of Δ P across the trial period. Error bars indicate a rather consistent level of uncertainties over time above 300W/m^2, power difference trends positively from 0% to slightly over 40% at 800W/m^2 (Figure 29). In this trial, lower power is evident below 300 Wm^2 but between 300W/m^2 and 800W/m^2, there is indication of higher irradiance possibly due to the varied geometry (Figure 29). Error bars indicate a small uncertainty across the plane of aperture data during the trial period.

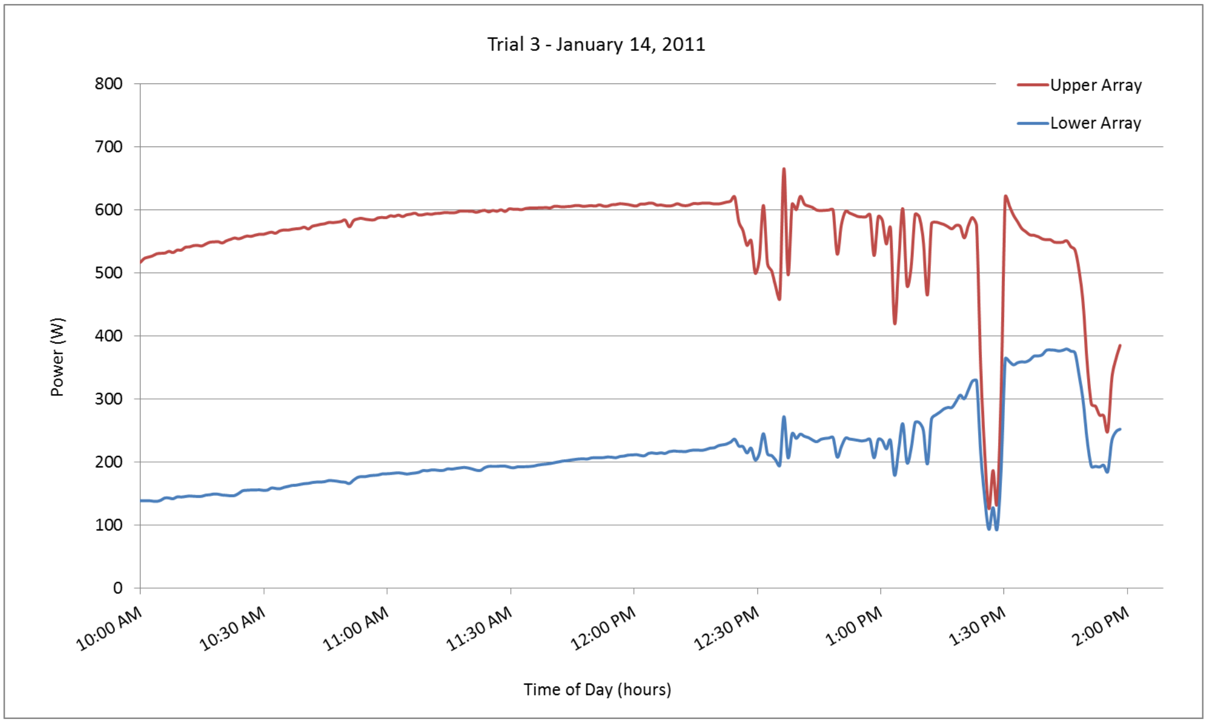

Figure 26. Chart of Trial 3. Power output on January 14, 2012. White TIOCOAT™-3 Modules, White TIOCOAT™ 3 Modules Horizontal.

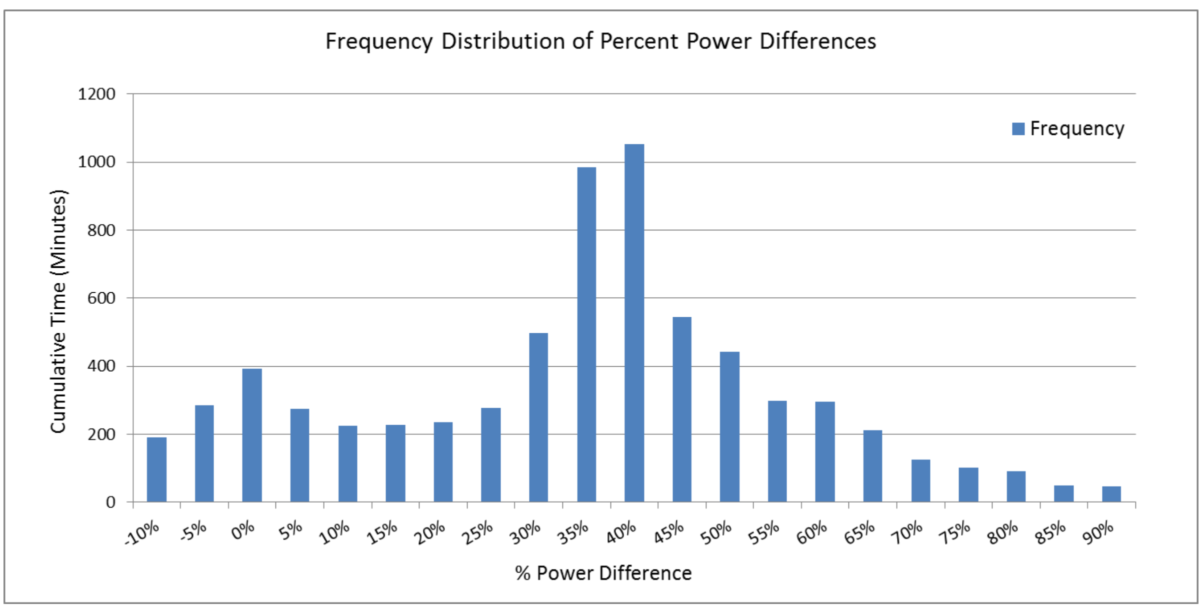

Figure 27. Chart of Trial 3. Frequency Distribution of Percent Power Differences

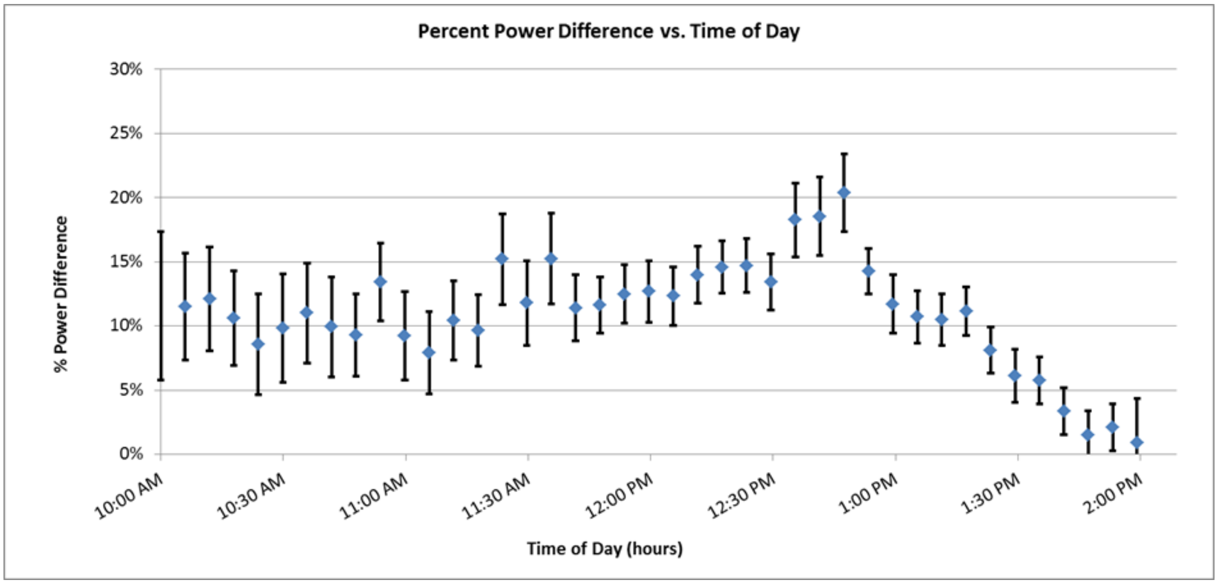

Figure 28. Chart of Trial 3. Percent Power Difference vs. Time of Day.

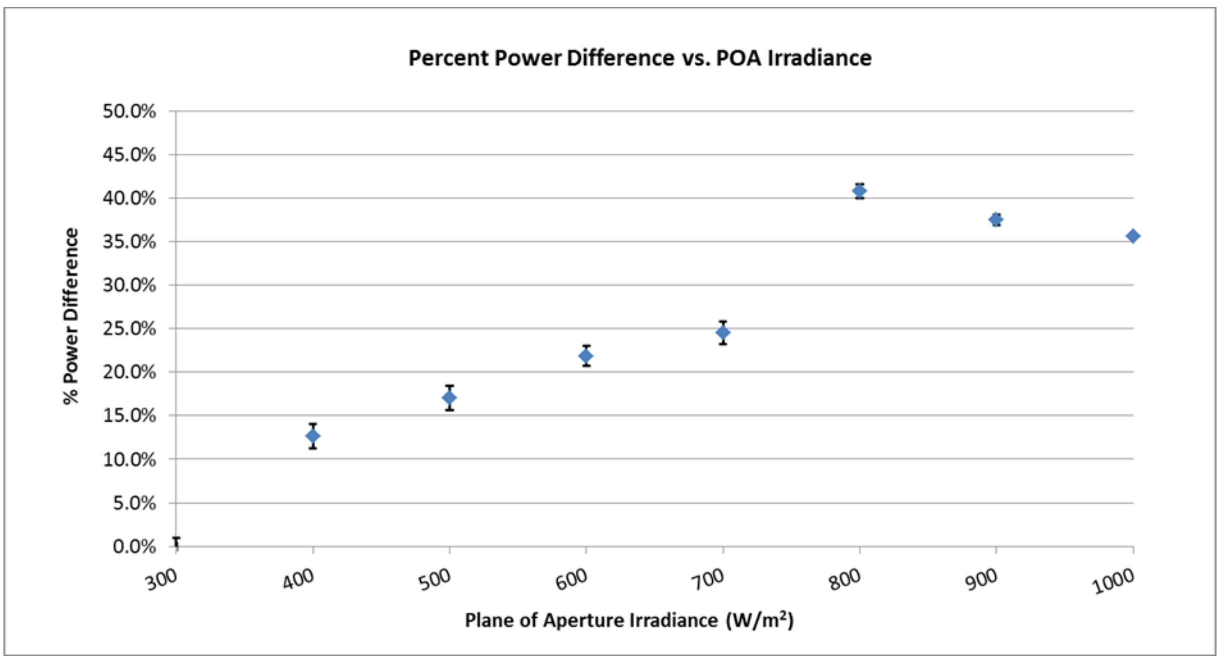

Figure 29. Chart of Trial 3. Percent Power Difference vs. POA.

Trial 4

January 30-February 22

The configuration of Trial 4 was modified so that both upper and lower arrays were identically mounted flush to the roof, 6 inches above TIOCOAT™ and SWARCO glass beads. The objective was to attempt to verify power output was identical for both arrays. As shown in Figure 30, for February 13, 2012, power output was nearly identical with minimal variation between arrays. Fluctuation in power output for both arrays was likely to be intermittent clouds during the day since the lowest power output was just below 200 watts during the trial period. It is possible to conclude that performance of these two arrays would be very similar on other days throughout this trial based on the overlap of the graphed lines.

For the complete Trial 4 period, power output was slightly higher in the upper array, but still falls within a normal distribution and shown in Figure 31. The average percent in power difference was 1.0 ± 0.1% with N=6,551. Between 10:00 a.m. and 11:00 a.m., the lower array consistently performed better by almost 3%, but percentage of power difference after that time appears to vary between upper and lower arrays (Figure 32). After 1:30 p.m. there is less uncertainty, but it would be difficult to suggest any type of pattern. At low plane of aperture irradiance, Figure 33 initially suggests the lower array performs better, but at 500W/m^2, the upper array outperforms the lower array by approximately 2% although the chart indicates greater uncertainty.

In summary, this trial was performed as a form of verification that both arrays would perform identically by using the same reflective material, same equipment, and the same time period. The attempt was to measure a difference in power of zero, but the trial actually netted a power difference of 1%. The result of this trial signifies that within all trials, there is a minimum 1% margin of error which indicates the difference in power must be greater than 1% to be considered greater that zero.

Since the reflective material and geometry of both arrays were identical, Trial 4 results, for the purpose of this scientific study, must be valued as a systematic uncertainty of ±1% which should be applied to all other trials in this study.

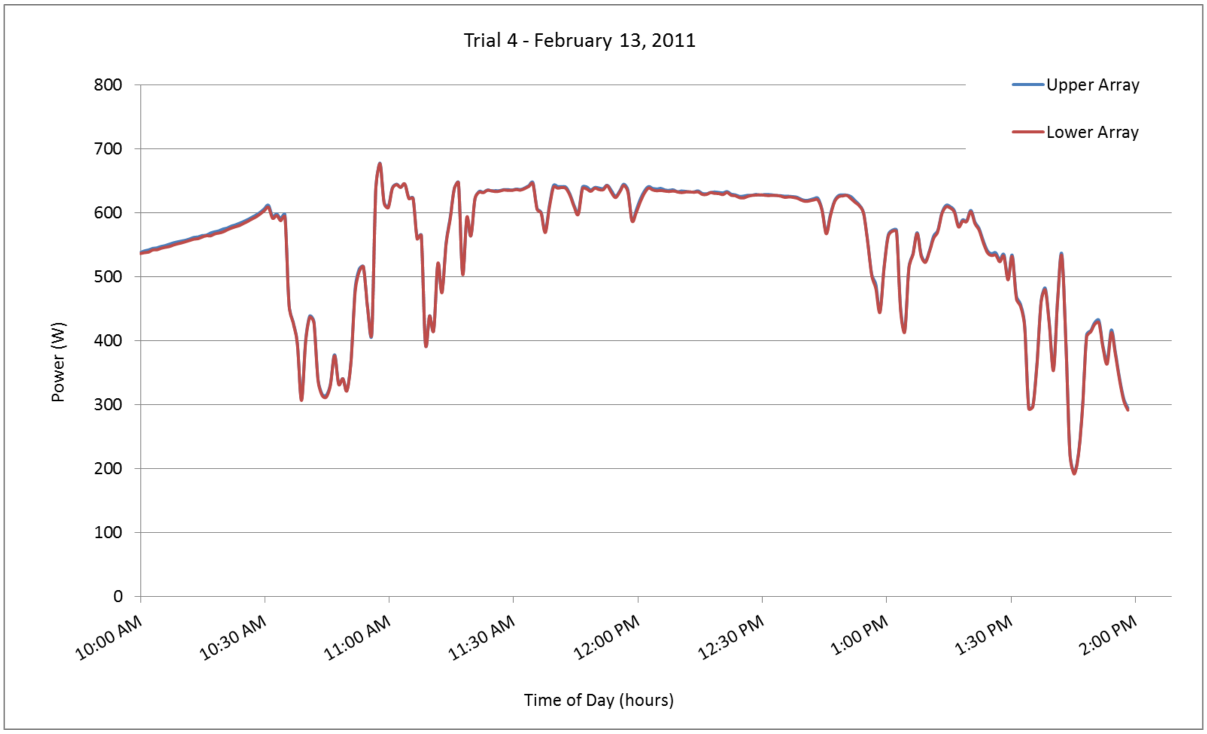

Figure 30. Chart of Trial 4. Power output on February 13, 2012. White TIOCOAT™ Flush 3 Modules White TIOCOAT™ Flush 3 Modules.

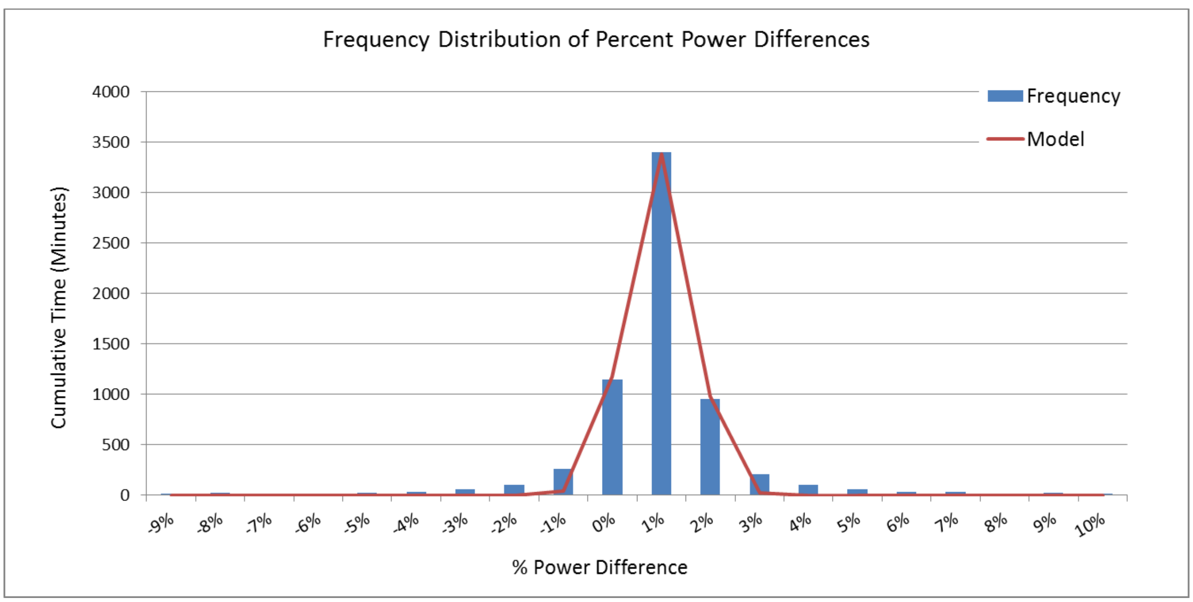

Figure 31. Chart of Trial 4. Frequency Distribution of Percent Power Differences

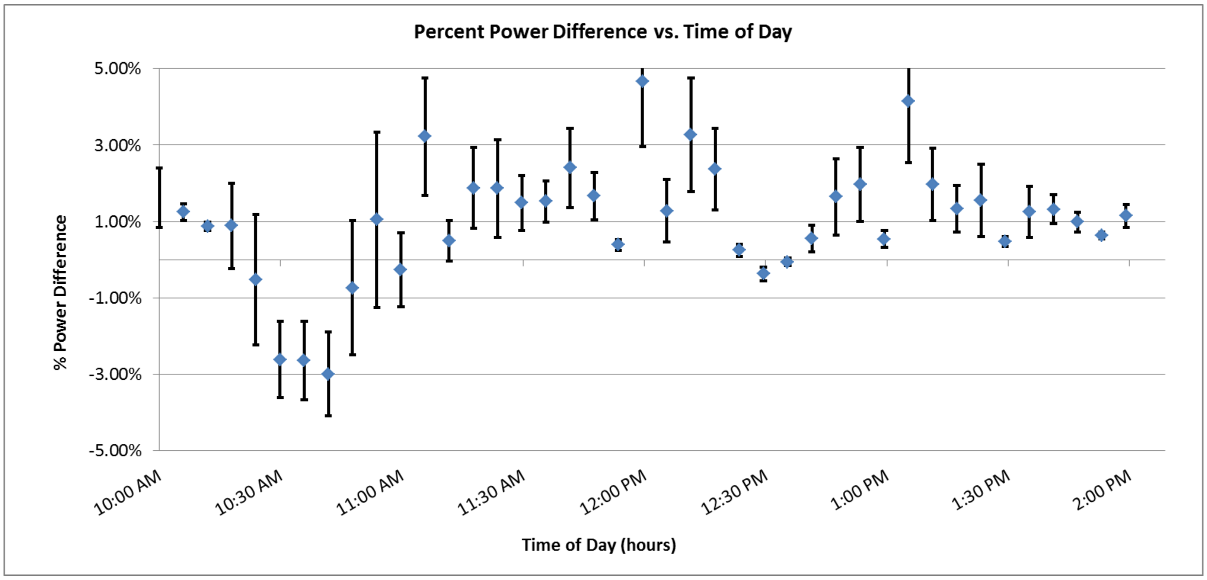

Figure 32. Chart of Trial 4. Percent Power Difference vs. Time of Day.

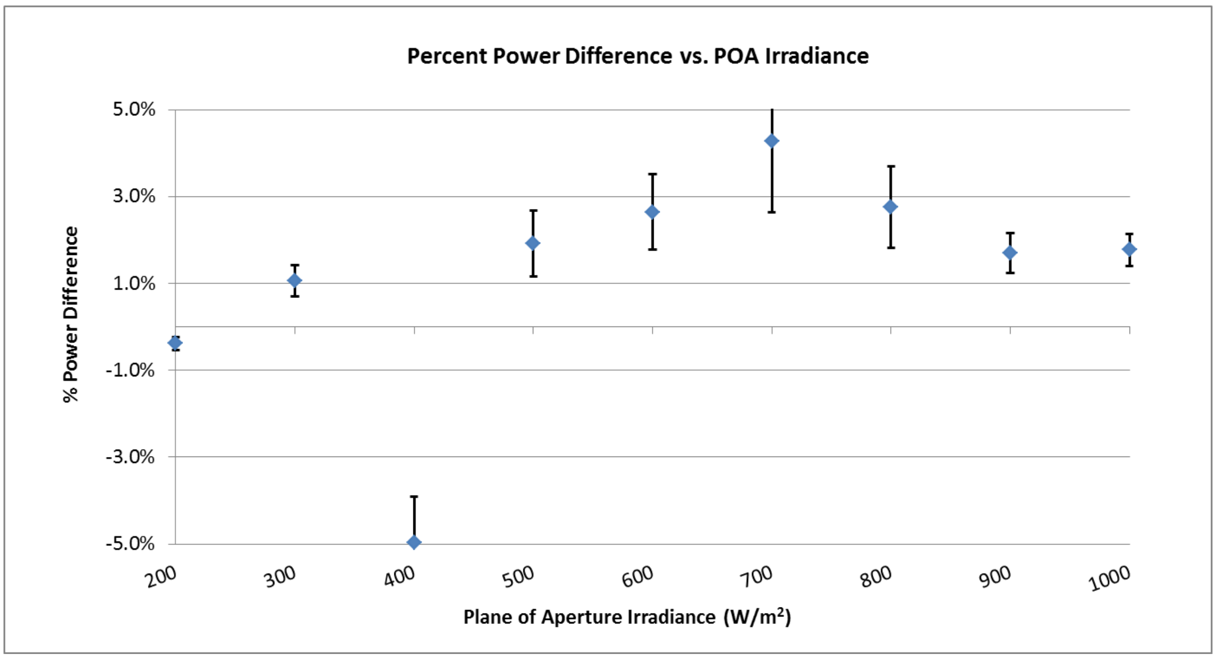

Figure 33. Chart of Trial 4. Percent Power Difference vs. POA Irradiance.

Trial 5

February 23-March 9

As noted in Trial 4, a systematic uncertainty of ±1% was found in the results. It important to realize that this systematic uncertainty must be viewed differently than the statistical uncertainty mentioned in each trial analysis, where all trial statistical uncertainties were less that 1%.

In Trial 5, the silver Benjamin Moore reflective surface was introduced under the upper array with the lower array utilizing TIOCOAT™ and SWARCO glass beads from the previous trial. Data from March 6, 2012 indicate relatively identical power output for both arrays and an exceptional clear day with very few fluctuations in power (Figure 34).

The distribution of percent power difference was similar to Trials 1, 2, and 4 as shown in Figure 35 with the upper array slightly outperforming the lower array, but distribution was normal. Average percent power difference was 1.0 ± 0.1% with N=4,587. Percent of power difference uncertainty was smaller before 10:30 a.m. for the upper array, but toward the middle of the day, uncertainties varied greatly with no particular pattern. There was a change in percent power difference of the lower array after 1:30 p.m., but the uncertainties are much greater indicating there was an event, but it is undeterminable what that event might be (Figure 36). The percent power difference peaks at 6% for aperture irradiance of 600W/m^{2,} as irradiance increases, the percent difference in power decreases. Additionally, smaller error bars are seen at irradiance (Figure 37).

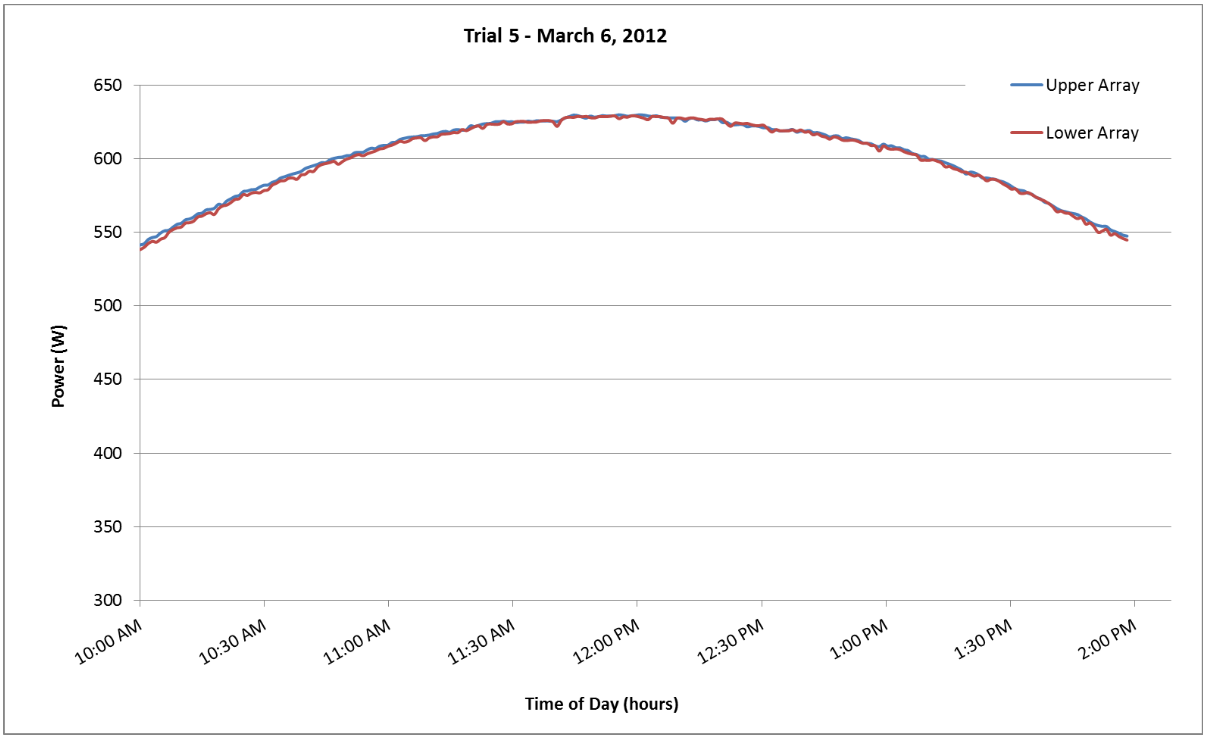

Figure 34. Chart of Trial 5. Power on March 6, 2012. Silver Roof Paint Flush 3 Modules, White TIOCOAT™ Flush 3 Modules.

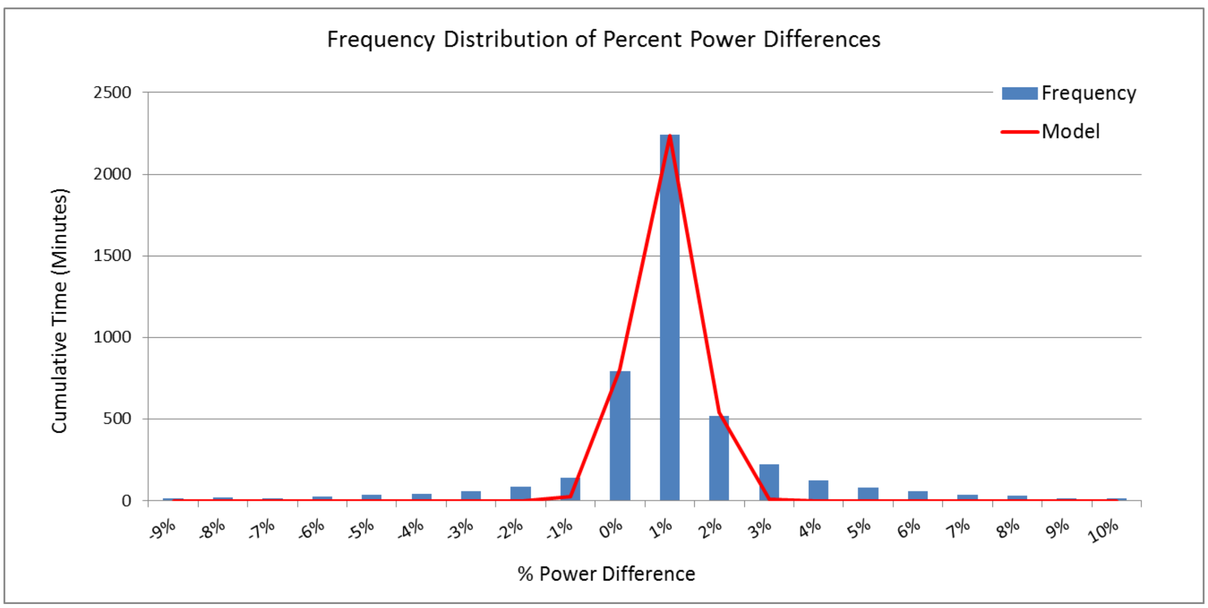

Figure 35. Chart of Trial 5. Frequency Distribution of Percent Power Differences

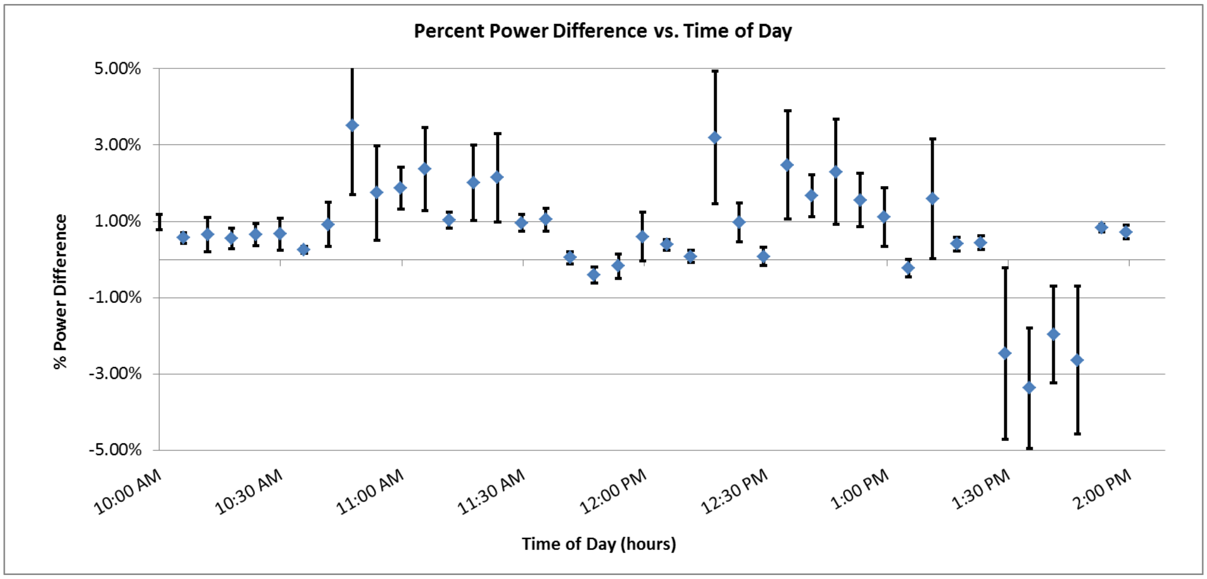

Figure 36. Chart of Trial 5. Percent Power Difference vs. Time of Day.

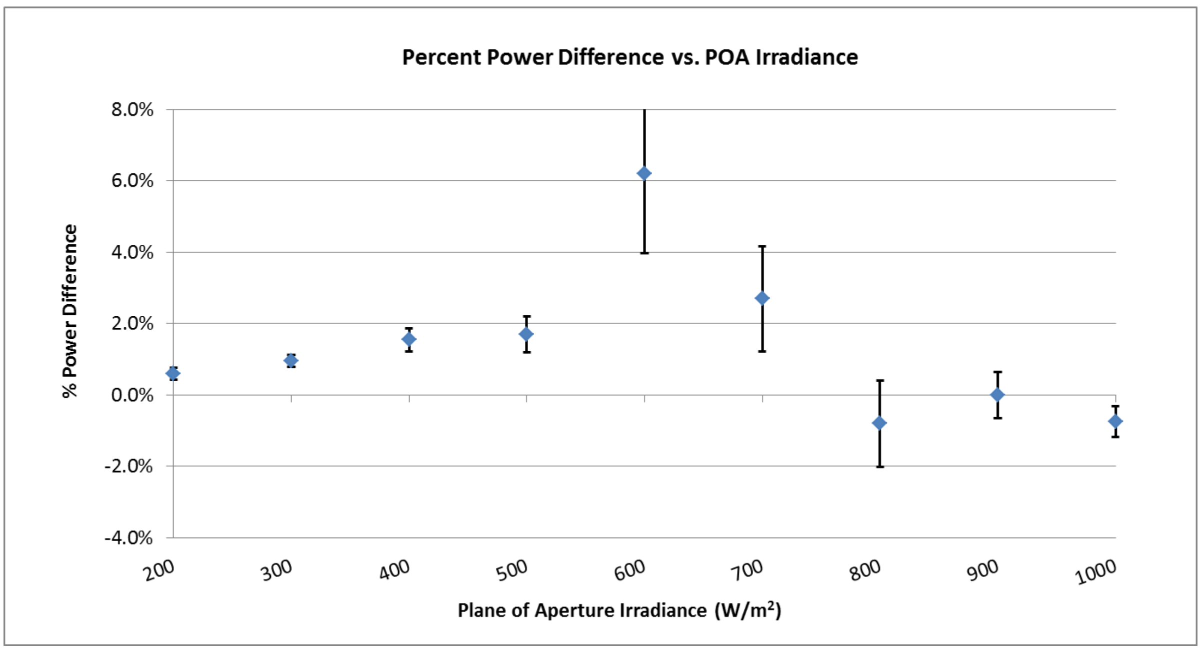

Figure 37. Chart of Trial 5. Percent Power Difference vs. POA Irradiance.

Trial 6

March 29 –April 30

Trial 6 had the same module configuration of three modules flush per array. The upper array utilized Benjamin Moore silver roof paint as the reflective material, and the lower array utilized medium brown shingles as the reflective material. The graph of power for April 1, 2012, suggests that upper array outperformed the lower array, but only slightly. The performance of the arrays was nearly identical with power varying between 150 watts and 500 watts as shown in Figure 38.

The frequency distribution in Figure 39 indicates the upper array outperformed the lower array by 4% and the lower array consistently performed more poorly over the trial period. The average percent power difference was 3.6 ± 0.1% with *N*=8,804. The Percent Power Difference vs. Time of Day chart illustrates a fairly consistent percentage power difference with a few periods of greater uncertainty, but clearly smaller uncertainties than the first five trials overall between 10:00 a.m. and 2:00 p.m. (Figure 40). Plane of aperture irradiance between 200W/m^2 and 1000 W/m^2 had a percent power difference around 3% throughout the duration of the trial (Figure 41).

In summary, the results from Trial 6 indicate that in fact, the reflective silver material did increase power over the medium brown shingles. Additionally, this trial had a higher confidence level overall noted by the smaller error bars in both Figure 40 and Figure 41.

Using the findings in Trial 5, we can then conclude that the difference in power for Trial 6, silver reflective material vs. medium brown shingles, would actually result in a difference in power of nearly 2% rather than nearly 3%.

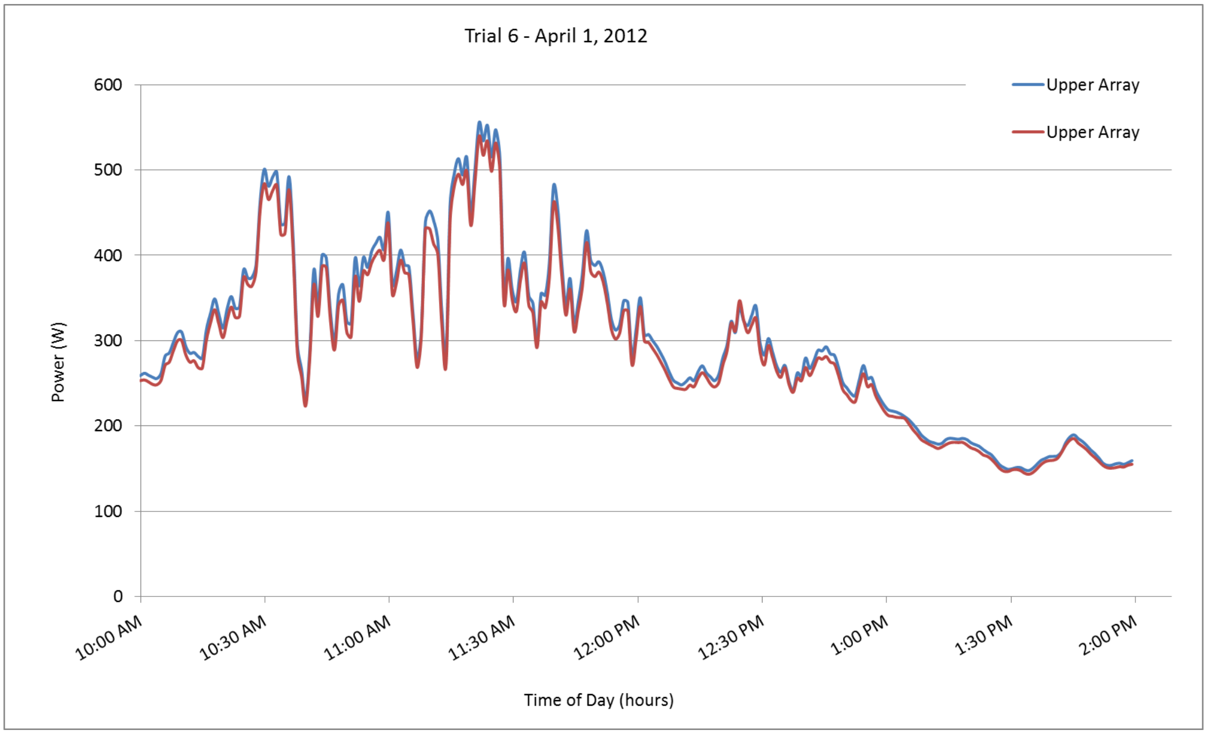

Figure 38. Chart of Trial 6. Power on April 1, 2012. Silver Roof Paint Flush 3 Modules, Shingles Flush 3 Modules.

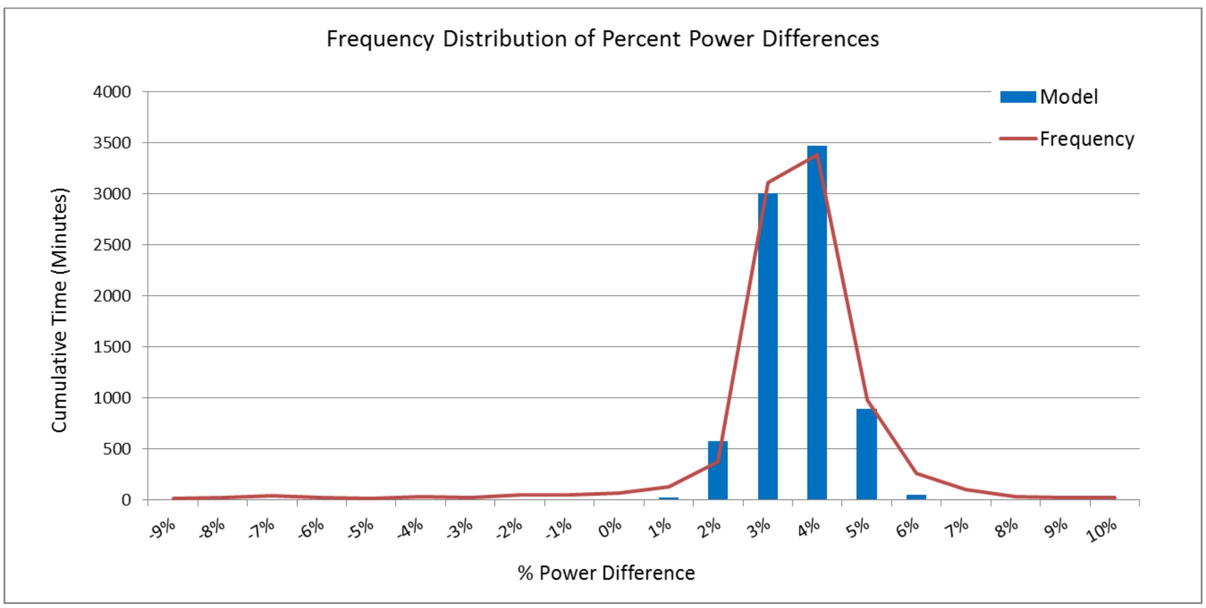

Figure 39. Chart of Trial 6. Frequency Distribution of Percent Power Differences.

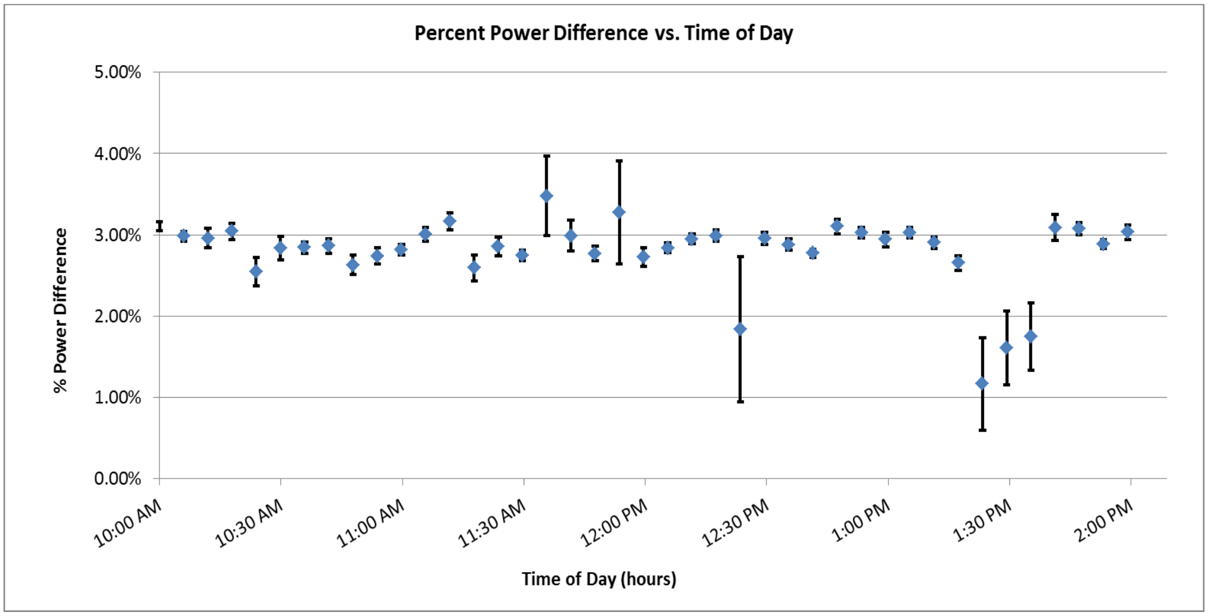

Figure 40. Chart of Trial 6. Percent Power Difference vs. Time of Day.

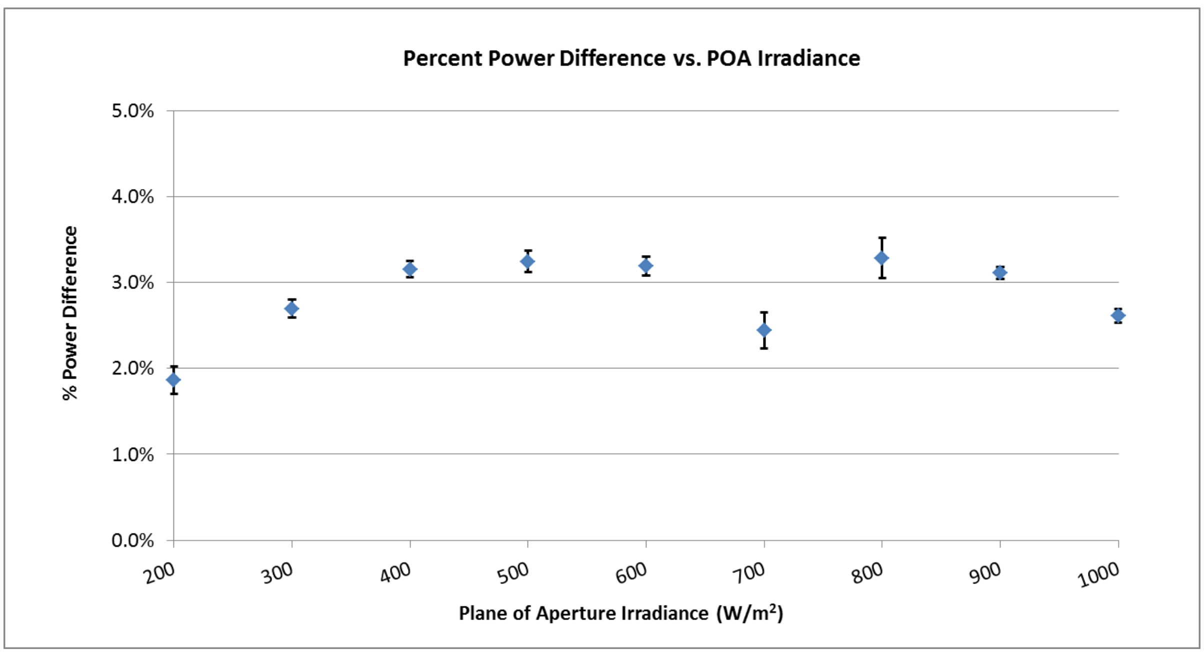

Figure 41. Chart of Trial 6. Percent Power Difference vs. POA Irradiance.

CHAPTER 5: CONCLUSION AND DISCUSSION

Summary

This study sought to verify Sanyo's claim of increased power of up to 30% when HIT Double Bifacial Modules are used. In an effort to increase in power produced by these modules, varying reflective materials and geometries were purposefully used under two separate arrays in six trials in the same location for a period of nearly five months. The study was conducted between late fall 2011 and early spring 2012 with a fairly typical winter for the Boone, North Carolina location.

To estimate the experimental systematic uncertainty, a trial was conducted (Trial 4) in which two nominally identical arrays were monitored. During this trial the mean of the distribution of percent power difference was 1%. This systematic uncertainty dominates the statistical uncertainty; therefore, an overall uncertainty of 1% will be applied to all percent power differences.

Reflective Materials

All three reflective materials are currently used in roofing applications. One variation was to scatter SWARCO glass beads onto the last wet coat of TIOCOAT before placing the material under the arrays. This procedure was atypical but it was an important step to this research, as these types of glass beads are applied to wet striping paint to mark safety areas on roadways. The additional reflectivity of the beads in combination with the white TIOCOAT™ was to significantly increase reflectivity. Trial 4 had both array flush mounted with TIOCOAT™ under each array.

The Benjamin Moore aluminum roof paint, while very reflective, lacked the bright white, but had somewhat of a mirror effect. The paint applied to canvas mimicked a metal roof surface and served as a reflective material for this study.

Trial 5 introduced this paint for the upper array, but retained SWARCO glass beads for the reflective material under the lower array. In this trial, the distribution of power differences was 1%

with the upper array slightly outperforming the lower array indicating that the power difference was consistent with zero.

The standard medium brown shingles, while not appearing reflective, actually reflect some light even though they were dark in color compared to the other two materials. Theses shingles could very well be installed under photovoltaic modules in a standard installation. In Trial 6, the silver paint was used under the upper array and the shingles were used under the lower array. The distribution of power differences was 4% with the upper array outperforming the lower array. Clearly, the silver paint assisted in increasing array power output over the medium brown shingles.

In summary, varying different reflective materials below the lower surface of the modules did little to increase power. It is conceivable to conclude that there is a possibility of increasing power by altering reflective material below the modules, but numerous variables such as array location, module distance from reflecting surface, geographic location, and maintenance of the arrays would be a few determining factors whether this escalation in power could be duplicated or possibly increased by careful planning.

Edge Placement

In Trial 1 and Trial 2, the upper array side edges were shaded with non-working modules. In these two trials, the reflective material extended all the way to the left and right of the unconnected modules on the upper array which physically had 5 modules. The reflective material for the lower array was the same size, but because there were on three modules in this array, the material extended 40.5 inches on either side of the left and right lower array of three modules. Reflective material was under all of modules throughout the entire study, and by visual inspection, the area under the non-working modules was not as exposed to as much light as the lower configuration with exposed edges.

Scientifically, this configuration of unconnected side modules on the upper array in Trial 1 produced no difference in power, but in Trial 2, the lower array outperformed the upper array, but the overall power difference remained consistent with zero percent. Further, varying different reflective materials below the lower surface of the modules did little to increase power.

Module Geometry

Since the Sanyo HIT 195 Bifacial Module application is versatile, Trial 3 geometry compared two geometries (upper array flush vs. lower array horizontal) to determine the effect of module placement both from a performance standpoint, as well as a practical application in the field. In this trial, the lower array racking was modified to raise the array to a horizontal position, while the upper array remained flush to the roof, and both arrays had TIOCOAT™ with SWARCO glass beads below as the reflective material. Two vital aspects of this trial are important, the first being the actual geometry, and the second being the fact that the horizontal array had the reflective material at a 36° angle from the bottom of the array. An assumption could be made that the upper array was receiving direct and diffuse irradiation, but the lower array was receiving more diffuse irradiation and less direct irradiation due to the array's angle. Test results were astounding with the difference in geometry.

Altered geometry had the greatest effect on power output with the flush array outperforming the horizontal array. Trial 3 results indicated that with the lower array of Sanyo bifacial modules mounted horizontally, power was drastically reduced by nearly 40% compared to the upper array that was mounted at 36° relative to horizontal and flush to the roof. It is possible to conclude that with horizontal placement of the bifacial arrays in this application, it was not the best geometric configuration to support the manufacturer's claim of a possible increase in power by 30%.

Percent Power Difference vs. Time

The time of day for measurements, (10 a.m.-2 p.m.) was the identical throughout all trials. Trial 1 had .03% power difference on average with sporadic elevated uncertainties. Trial 2 power difference went from -8% near 10 a.m. to 8% at noon and dropped to -4% at 2 p.m. varying greatly from Trial 1. Additionally, there was much greater uncertainty at morning and noon times than at 2 p.m. Both of these trials had an unconnected module on each side of the upper array. In Trial 3 power differences vs. time of day was the most pronounced at 12%, 2% and 1% with much higher uncertainty at 10 a.m. and 12 p.m. This trial also had the varied geometry on the lower array. Trial 4 power difference varied -3%, 2% and 1% respectively with higher uncertainty at 10 a.m. and 12 p.m. Trial 5 power differences ranged from 1%, 1.5%, .5% and -3% in the four hour period with no noticeable trend over time. Trial 6 was rather consistent with a difference in power at 3% with very little uncertainty (smaller error bars) during the trial period.

Trial 3 power difference trend was much less sporadic than Trial 1 and Trial 2. While the did not have an apparent power difference trend, but Trial 5 trended around 1% with sporadic increases of greater uncertainty throughout the trial period. Trial 6 indicated the most stable power difference across the trial with less uncertainty.

In summary, there were no consistent trends in percent power vs. time of day until Trial 6. Percent power difference was around 3% with little uncertainty (small error bars) throughout the trial period.

Percent Power Difference vs. POA Irradiance

Trial 1 power difference vs. plane of aperture irradiance varied from .75% at 300W/m², to .5% at 1000W/m² with greater uncertainty early in the day. Trial 2 power difference was .5% to a high of 4% with greater uncertainty. Both of these trials utilized the unconnected module on either side on the upper array. Trial 3 power difference was 13% at 400W/m² to 41% at 800W/m². In this trial, the varied geometry was implemented. Trial 4 power differences were .5% at 200W/m², but rose to 5% at 400W/m² and to 3.75% at 700W/m² with the greatest uncertainty toward the end of the day. In this trial both arrays were flush mounted and had TIOCOAT™ with SWARCO glass beads as the reflective material. Trial 5 power differences was .5% at 200W/m², 2% at 500W/m², 6% at 600W/m² and -.5% at 800W/m², utilizing the silver aluminum paint for the upper array and

TIOCOAT™ with SWARCO glass beads for the lower array. Geometry was the same for both arrays. For Trial 6, the power difference was the most consistent at 3% with very little uncertainty.

Percent power difference for Trial 1 showed a steady decreasing trend from .75% to .5% with increasing POA irradiance, whereas Trial 2 had a steady increase from .5% peaking at 4% but dropped at 900W/m^2. Trial 3 trended similarly to Trial 2, but percent power difference was much greater due the varied geometry of the arrays. Trial 4 also tended to show a consistent increase in power from -.5% to 3.6% at700W/m^2 before declining to 1.3% at 1000W/m^2. Trial 5 displayed a peak near 6% at 600W/m^2, but had the highest level of uncertainty, while percent power difference at low and high irradiance were consistently between 0% and 1%. The least amount of variation in percent power difference was in Trial 6, which was rather level and had lower uncertainty across the trial period.

In summary, for Trial 1 the lower array performed better overall, but in Trial 2 the upper array performed better. The use of the mock panels on both of these trials with shingles and TIOCOAT™ respectively, did not show any particular similar trend. There was not any specific trend with Trial 4 and Trial 5, but the uncertainty was much greater than any other trial. Trial 6 had a very consistent power difference vs. POA and had the least uncertainty of all the trials. The upper array outperformed the lower array by approximately 3% ± 1% across all POA irradiance values. In most trials, the percent power difference starts low, peaks toward the middle and decreases at higher irradiance.

There were varying trends in percent power difference vs. POA across the trials. Trial 1 percentage was .75% at 300 W/m^2 and tapered to .5% at 1000 W/m^2. With trials 2, 3, 4 and 5 percentage power increased with irradiance between 600W/m^2 and 800W/m^2, then declined slowly toward 1000W/m^2. Trial 6 percentage power difference vs. POA irradiance was around 3%.

Applications

Purchasing the Sanyo HIT Double Bifacial Modules solely for the purpose of increasing power with the ability to use fewer modules would seem to be an unwise investment, but findings in this study could not deem this idea totally unreasonable. Rather, the use of these semi-translucent modules should be considered an opportunity to produce power within architectural applications not previously realized. The modules may also be used in ballasted mounts on a flat roof as well as in combination with a reflective roof surface such as TIOCOAT™; however array geometry is vital in all types of installation.

Sanyo engineered the HIT Double Bifacial Module to be installed at a variety of angles, but review of their company literature would seem to indicate installations of modules are mostly mounted horizontally in canopy type structures. While this type of installation is well within the product's specifications, research indicates the best position for a photovoltaic module is perpendicular to the sun's rays to absorb maximum irradiation.

The Sanyo HIT 195 Bifacial Modules would be beneficial in residential applications where space for conventional photovoltaic modules is limited. Careful planning in new construction and remodels could utilize the modules on porch roofs, skylights, or in canopies. In commercial urban areas, the modules would work nicely on flat or skywalk roofs without being visually intrusive.

For some, photovoltaic modules are considered unattractive and installation would be frowned upon. Integration of bifacial modules within structures would help minimize some of the negative responses by these individuals. Acceptance rates would most likely increase as innovative installation techniques are practiced.

Additional Research Opportunities

The research conducted in this study is far from conclusive for these modules, and in all fairness to Sanyo North America, the bifacial modules are definitely useful in a variety of installations. Further research would be needed to determine the return on investment of bifacial modules vs. conventional monofacial modules. Large scale, long term testing would especially be useful since solar azimuth changes over the course of the year. Additionally, photovoltaic modules are more efficient in cooler weather; as ambient temperature increases, performance decreases.

Additional research is needed including installing the bifacial modules in varying applications and locations tested over a longer period of time. Conversations pertaining to installation of these particular bifacial modules in the roof of bus shelters on a university campus would help indicate their worth over time. The same equipment used for this study could be used to retrofit three of the bus shelter installations. A small glass enclosure within the bus shelter structure would allow for visual inspection of the power inverter and would allow users of the bus shelter to view power generated over a time frame raising awareness of energy efficiency, technology, and photovoltaic integration in a real life application.

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APPENDIX A: SANYO HIT 195 SPECIFICATIONS DATA SHEET

Panasonic
ideas for life

Bifacial Photovoltaic Module

HIT® Double 195

VBHB195DA03

Power per Square Foot up to 19.1 Watts

Bifacial Effect
The back face of HIT Double solar panels generates electricity from ambient light reflected off surrounding surfaces, and combines with power from the front face of the panel. Dependant upon system design and site albedo, this results in up to 30% higher power generation (more kWh) per square foot.

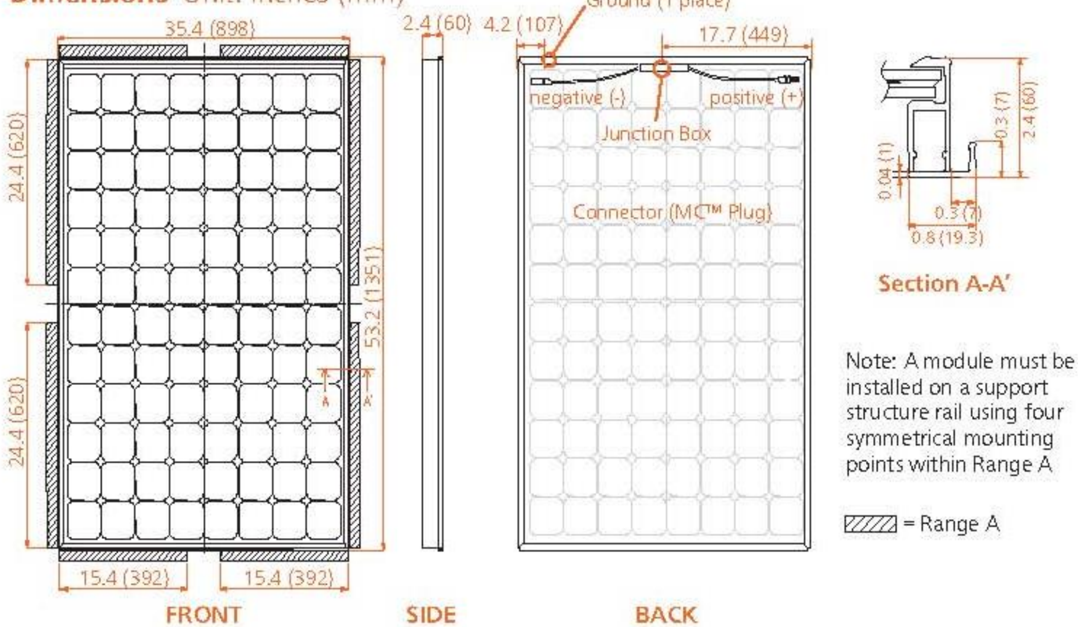
Application Possibilities
- Architectural, Awnings, Balconies, Bus Shelters, BIPV
- Deck & Porch Coverings, Canopies, Carports, Facades
- Fences, Siding, Trellises, Tracking Systems

High Temperature Performance
As temperatures rise, HIT Double solar panels produce more electricity than conventional solar panels at the same temperature, for good performance in high temperature sites.

Quality Products
The packing density of the panels reduces transportation, fuel, and storage costs per installed watt.

American Made Quality
Our silicon wafers are made in Oregon, USA and assembled in Mexico at SANYO's certified factory. ISO 9001(quality), 14001 (environment), 18001 (safety).

Dimensions Unit: inches (mm)



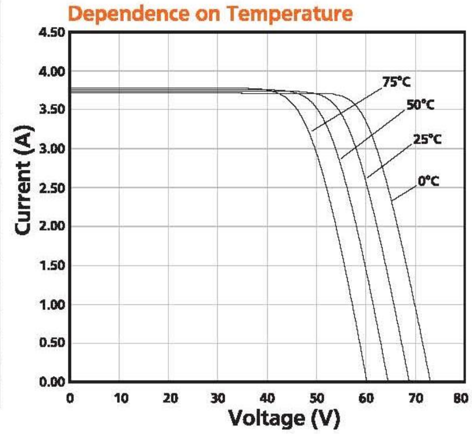
Note: A module must be installed on a support structure rail using four symmetrical mounting points within Range A

HIT® Double 195

Electrical Specifications

		Specifications Including Backside Irradiation Contribution in ISC as a Percent of STC					
Model VBHB195DA03	STC [1]	5%	10%	15%	20%	25%	30%
Rated Power (Pmax) [1]	195 W	204 W	213 W	222 W	231 W	240 W	249 W
Maximum Power Voltage (Vpm)	55.8 V	55.8 V	55.8 V	55.9 V	56.0 V	56.0 V	56.1 V
Maximum Power Current (Ipm)	3.5 A	3.66 A	3.82 A	3.97 A	4.13 A	4.29 A	4.45 A
Open Circuit Voltage (Voc)	68.7 V	68.9 V	69.0 V	69.1 V	69.2 V	69.2 V	69.5 V
Short Circuit Current (Isc)	3.73 A	3.92 A	4.10 A	4.29 A	4.48 A	4.66 A	4.85 A
Max. System Voltage (Vsys)	600 V	—	—	—	—	—	—
Series Fuse Rating	15 A	—	—	—	—	—	—
Temperature Coefficient (Pmax)	-0.34%/°C	—	—	—	—	—	—
Temperature Coefficient (Voc)	-0.192 V/°C	—	—	—	—	—	—
Temperature Coefficient (Isc)	1.70 mA/°C	—	—	—	—	—	—
Warranted Tolerance	+10/-0%	—	—	—	—	—	—
Cell Efficiency	19.3%	—	—	—	—	—	—
Module Efficiency [2]	16.1%	16.8%	17.6%	18.3%	19.0%	19.8%	20.5%
Power per Square Foot	14.9 W	15.6 W	16.3 W	17.0 W	17.7 W	18.4 W	19.1 W

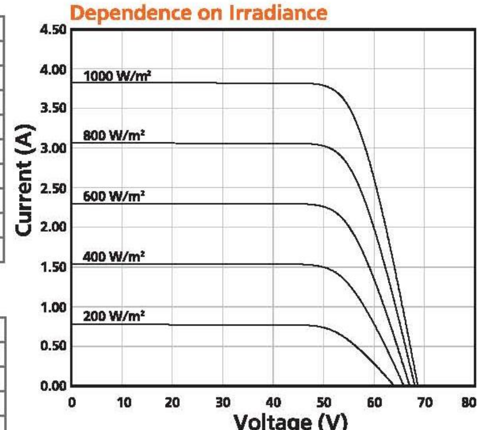
Dependence on Temperature



Mechanical Specifications

Internal Bypass Diodes	4 Bypass Diodes
Module Area	13.06 Ft² (1.21m²)
Module Weight	50.7 Lbs. (23kg)
Module Dimensions LxWxH	53.2 x 35.35 x 2.36 in. (1351 x 898 x 60 mm)
Cable Lengths	39.4 in. each (1000 mm)
Cable Size / Connector Type	No. 12 AWG / MC3™ Connectors
Static Load	50 PSF (2400 Pa)
Pallet Dimensions LxWxH	54.3 x 36 x 70.1 in. (1379 x 912 x 1781 mm)
Full Pallet Quantity & Weight	20 pcs. / 1014 Lbs. (460 kg)
Quantity per 20'/40'/53' Container	200 pcs., 420 pcs., 540 pcs.

Dependence on Irradiance



Safety Ratings & Limited Warranty

Fire Safety Classification	Class A
Hail Safety Impact Velocity	1" hailstone (25mm) at 52 mph (23m/s)
NOCT (°C)	113°F (45°C)
Safety & Rating Certifications	UL 1703, cUL, CEC
Limited Warranties	10 Years Workmanship, 20 Years Power Output

[1] Standard Test Conditions: Cell Temperature 25°C, Air Mass 1.5, 1000 W/m²
[2] Equivalent module efficiency, including power from the back face.
Note: Specifications and information above may change without notice.

To Maximize Power

1. Elevate panels above a surface as much as possible.
2. Place panels over light-colored surfaces.
3. Do not allow support rails to shade the panel's back face.

IMPORTANT:
The rated power of HIT® Double bifacial solar panels is measured under Standard Test Conditions (STC). STC does not account for power produced from the back face of panels. Therefore, HIT Double panels will produce more power than their STC rating, up to 30% more, depending upon the system design and site albedo.Account for the additional power when sizing, selecting system components and wiring.

⚠ **CAUTION!** Please read the installation manual carefully before using the products.

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Panasonic®

04/2012

APPENDIX B: SUNNY BOY 700-US SPECIFICATIONS SHEET

SUNNY BOY 700-US

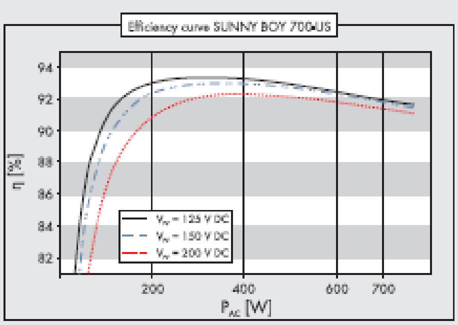
UL Certified	Safe	Simple	Flexible
• For countries that require UL certification (UL 1741/IEEE 1547)	• Galvanic isolation due to integrated transformer	• Simple installation thanks to three-point mounting assembly	• Three different input voltage ranges • Modular addition for all applications

SUNNY BOY 700-US

The versatile choice for any system configuration

The SMA Sunny Boy 700-US was SMA's first mass-produced string inverter and it continues to enjoy immense popularity in today's solar market. Its compact size and economical price make it ideal for starter or demonstration systems. It is also perfectly suited for adding a bit more power to an existing solar system. Its modular design makes expansion to almost any size easy. Three different configurable input voltage ranges make the Sunny Boy 700-US a versatile choice, whatever your system configuration.

Technical data	SB700-US 150 V DC	SB700-US 200 V DC	SB700-US 250 V DC
Input (DC)			
Max. recommended PV power (@ module STC)	575 W	750 W	875 W
Max. DC power (@ cos φ = 1)	510 W	670 W	780 W
Max. DC voltage	150 V	200 V	250 V
DC nominal voltage	95 V	125 V	150 V
MPP voltage range	77 V - 120 V	100 V - 160 V	125 V - 200 V
Min. DC voltage / start voltage	75 V / 95 V	100 V / 125 V	125 V / 150 V
Max. input current / per string		7 A / 7 A	
Number of MPP trackers / strings per MPP tracker		1 / 2	
Output (AC)			
AC nominal power	460 W	600 W	700 W
Max. AC apparent power	460 VA	600 VA	700 VA
Nominal AC voltage / adjustable		120 V / –	
AC voltage range		106 V - 132 V	
AC grid frequency; range		60 Hz; 59.3 - 60.5 Hz	
Max. output current	4.4 A	5.7 A	6.6 A
Power factor (cos φ)	1	1	1
Phase conductors / connection phases	1 / 1	1 / 1	1 / 1
Harmonics	< 3%	< 3%	< 3%
Efficiency			
Max. efficiency	92.4%	93.3%	93.6%
CEC efficiency	91.5%	91.5%	91.5%
Protection devices			
DC reverse-polarity protection	●	●	●
AC short circuit protection	●	●	●
Galvanically isolated / all-pole sensitive monitoring unit	● / –	● / –	● / –
Protection class / overvoltage category	I / III	I / III	I / III
General data			
Dimensions (W / H / D) in mm (in)		322 / 290 / 180 (13 / 11 / 7)	
DC disconnect dimensions (W / H / D) in mm (in)		–	
Packing dimensions (W / H / D) in mm (in)		390 / 390 / 230 (15 / 15 / 9)	
DC disconnect packing dimensions (W / H / D) in mm (in)		–	
Weight / DC disconnect weight		23 kg (51 lb) / –	
Packing weight / DC disconnect packing weight		26 kg (57 lb) / –	
Operating temperature range (full power)		-25 °C ... +45 °C (-13 °F ... +113 °F)	
Noise emission (typical)	–	–	–
Internal consumption at night	0.1 W	0.1 W	0.1 W
Topology	LF transformer	LF transformer	LF transformer
Cooling concept	convection	convection	convection
Electronics protection rating / connection area	NEMA 3X / NEMA 3X	NEMA 3X / NEMA 3X	NEMA 3X / NEMA 3X
Features			
Display: text line / graphic	● / –	● / –	● / –
Interfaces: RS485 / Bluetooth	○ / –	○ / –	○ / –
Warranty: 10 / 15 / 20 years	● / ○ / ○	● / ○ / ○	● / ○ / ○
Certificates and permits (more available on request)		UL1741, UL1998, IEEE 1547, FCC Part 15 (Class A & B), CSA C22.2 No. 107.1-2001	
Data at nominal conditions			
● Standard features ○ Optional features – Not available			
Type designation	SB 700U 150 VDC	SB 700U 200 VDC	SB 700U 250 VDC



Accessories

RS485 interface
485USPB-NR

APPENDIX C: CAMPBELL SCIENTIFIC CR1000 SPECIFICATIONS SHEET

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C range unless otherwise specified; non-condensing environment required. To maintain electrical specifications, Campbell Scientific recommends recalibrating dataloggers every two years. We recommend that the system configuration and critical specifications are confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE
10 ms to one day @ 10 ms increments

ANALOG INPUTS (SE1-SE16 or DIFF1-DIFF8)
8 differential (DF) or 16 single-ended (SE) individually configured. Channel expansion provided by AM16/32B and AM25T multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single conversion. Resolution of DF measurements with input reversal is half the Basic Res.

Range (mV)[1]	*DF Res (µV)*[2]	*Basic Res (µV)*
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

[1]Range overhead of ~9% on all ranges guarantees that full-scale values will not cause over range.
[2]Resolution of DF measurements with input reversal.

ACCURACY[3]:
±(0.06% of reading + offset), 0° to 40°C
±(0.12% of reading + offset), -25° to 50°C
±(0.18% of reading + offset), -55° to 85°C (-XT only)

[3]Accuracy does not include the sensor and measurement noise. The offsets are defined as:
Offset for DF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3·Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range; digital resolution dominates for higher ranges.
250 µs Integration: 0.34 µV RMS
50/60 Hz Integration: 0.19 µV RMS

ANALOG MEASUREMENT SPEED:

Integration Type/ Code	*Integration Time*	*Settling Time*	*Total Time*[5]	
			SE w/ No Rev	*DF w/ Input Rev*
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[4]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[4]	20.00 ms	3 ms	~25 ms	~50 ms

[4]AC line noise filter.
[5]Includes 250 µs for conversion to engineering units.

INPUT LIMITS: ±5 V

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 Gohms typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.3°C, -25° to 50°C
±0.8°C, -55° to 85°C (-XT only)

ANALOG OUTPUTS (Vx1-Vx3)
3 switched voltage, active only during measurement, one at a time.

RANGE AND RESOLUTION: Voltage outputs programmable between ±2.5 V with 0.67 mV resolution.

V_x ACCURACY: ±(0.06% of setting + 0.8 mV), 0° to 40°C
±(0.12% of setting + 0.8 mV), -25° to 50°C
±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

V_x FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

CURRENT SOURCING/SINKING: ±25 mA

RESISTANCE MEASUREMENTS
MEASUREMENT TYPES: The CR1000 provides ratiometric measurements of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Precise, dual polarity excitation using any of the 3 switched voltage excitations eliminates dc errors.

VOLTAGE RATIO ACCURACY[6]: Assuming excitation voltage of at least 1000 mV, not including bridge resistor error.

±(0.04% of voltage reading + offset)/V_x

[6]Accuracy does not include the sensor and measurement noise. The offsets are defined as:
Offset for DF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3·Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

Offset values are reduced by a factor of 2 when excitation reversal is used.

PERIOD AVERAGE
Any of the16 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	*Input Range (±mV)*	*Signal (peak to peak)*[7]		*Min Pulse Width (µV)*	*Max*[8] *Freq (kHz)*
		Min. (mV)	*Max (V)*		
1	2500	500	10	2.5	200
10	250	10	2	10	50
33	25	5	2	62	8
100	2.5	2	2	100	5

[7]With signal centered at the datalogger ground.
[8]The maximum frequency = 1/(Twice Minimum Pulse Width) for 50% of duty cycle signals.

PULSE COUNTERS (P1-P2)
(2) inputs individually selectable for switch closure, high frequency pulse, or low-level ac. Independent 24-bit counters for each input.

MAXIMUM COUNTS PER SCAN: 16.7×10^6

SWITCH CLOSURE MODE:
Minimum Switch Closed Time: 5 ms
Minimum Switch Open Time: 6 ms
Max. Bounce Time: 1 ms open w/o being counted

HIGH-FREQUENCY PULSE MODE:
Maximum Input Frequency: 250 kHz
Maximum Input Voltage: ±20 V
Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

LOW-LEVEL AC MODE: Internal AC coupling removes AC offsets up to ±0.5 V.

Input Hysteresis: 12 mV @ 1 Hz
Maximum ac Input Voltage: ±20 V
Minimum ac Input Voltage:

Sine Wave (mV RMS)	*Range(Hz)*
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

DIGITAL I/O PORTS (C1-C8)
8 ports software selectable, as binary inputs or control outputs. Also provide edge timing, subroutine interrupts/wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UART), SDI-12 communications, and SDM communications.

HIGH-FREQUENCY MAX: 400 kHz

SWITCH CLOSURE FREQUENCY MAX: 150 Hz

EDGE TIMING RESOLUTION: 540 ns

OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low <0.1

OUTPUT RESISTANCE: 330 ohms

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 kohms

SWITCHED 12 V (SW-12)
One independent 12 V unregulated sources switched on and off under program control. Thermal fuse hold current = 900 mA @ 20°C, 650 mA @ 50°C, 360 mA @ 85°C.

CE COMPLIANCE
STANDARD(S) TO WHICH CONFORMITY IS DECLARED: IEC61326:2002

COMMUNICATIONS
RS-232 PORTS:
9-pin: DCE port for battery-powered computer or non-CSI modem connection.
COM1 to COM4: Four independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 VUART
Baud Rates: selectable from 300 bps to 115.2 kbps.
Default Format: 8 data bits; 1 stop bits; no parity
Optional Formats: 7 data bits; 2 stop bits; odd, even parity

CS I/O PORT: Interface with CSI peripherals

SDI-12: Digital control ports 1, 3, 5, and 7 are individually configured and meet SDI-12 Standard version 1.3 for datalogger mode. Up to ten SDI-12 sensors are supported per port.

PERIPHERAL PORT: 40-pin interface for attaching CompactFlash or Ethernet peripherals

PROTOCOLS SUPPORTED: PakBus, Modbus, DNP3, FTP, HTTP, XML, POP3, SMTP, Telnet, NTCIP, NTP, SDI-12, SDM

CPU AND INTERFACE
PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core)

MEMORY: 2 MB of Flash for operating system; 4 MB of battery-backed SRAM for CPU usage, program storage and data storage.

CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

SYSTEM POWER REQUIREMENTS
VOLTAGE: 9.6 to 16 Vdc (reverse polarity protected)

EXTERNAL BATTERIES: 12 Vdc nominal

TYPICAL CURRENT DRAIN:
Sleep Mode: 0.7 mA (0.9 mA max.)
1 Hz Sample Rate (1 fast SE meas.): 1 mA
100 Hz Sample Rate (1 fast SE meas.): 16.2 mA
100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 27.6 mA
Optional Keyboard Display On (no backlight): add 7 mA to current drain
Optional Keyboard Display On (backlight on): add 100 mA to current drain

PHYSICAL
DIMENSIONS: 9.4" x 4" x 2.4" (23.9 x 10.2 x 6.1 cm); additional clearance required for serial cable and sensor leads.

WEIGHT: 2.1 lbs (1 kg)

WARRANTY
3-years against defects in materials and workmanship.

Campbell Scientific, Inc. | 815 W 1800 N | Logan, Utah 84321-1784 | (435) 753-2342 | www.campbellsci.com
USA | AUSTRALIA | BRAZIL | CANADA | COSTA RICA | ENGLAND | FRANCE | GERMANY | SOUTH AFRICA | SPAIN

APPENDIX D: OHIO SEMITRONICS PC8-004-08X5 SPECIFICATIONS SHEET

OSI DC & VARIABLE-FREQUENCY AC WATT TRANSDUCER *MODEL* PC8-

DC WATTS

DESCRIPTION

The PC8 units are designed to provide accurate power measurements on sinusoidal or highly-distorted waveforms. Basic four-quadrant multiplier response of dc to 20 kilohertz provides operation up to at least the fifth harmonic for dc to 400-hertz applications.

Full-scale accuracy of 1% results for dc, sinusoidal ac, chopped or pulsed waveforms. Time-varying waveforms with a dc component are accurately measured.

Most units provide bidirectional output so that power consumption or generation can be measured. All units have input/output/case isolation.

Standard units with input current ranges up to 2000 Amperes and voltage ranges to 600 Volts are available with outputs to interface with most data calibration or control equipment.

FEATURES

- Accurate from dc to 400 Hz.
- Factory calibration tr able to NIST.
- Input/output/case isolation.
- Real-time indication of power with transient response of less than 50 microseconds.

APPLICATIONS

- Accurate monitoring of power that contains dc and/or harmonics.
- Ideal for use in SCR and other ac or dc switching circuitry.
- Bidirectional output.

MODEL SELECTION

PC8 --- 004 --- 08 --- X5 (S)

INPUT VOLTAGE	INPUT CURRENT	SENSOR SIZE	OUTPUT OPTIONS
(001) = 0 - 25V	(08) = 0 - 5A	(internal)	(B) = 0 - ±1mAdc
(002) = 0 - 50V	(01) = 0 - 100A	C	(D) = 0 - ±10Vdc
(003) = 0 - 150V	(02) = 0 - 200A	D	(E) = 4 - 20mAdc
(004) = 0 - 300V	(03) = 0 - 300A	D	(EM) = 4/12/20mAdc
(005) = 0 - 400V	(04) = 0 - 400A	D	(X5) = 0 - ±5Vdc
(006) = 0 - 500V	(05) = 0 - 600A	E	
(007) = 0 - 600V	(06) = 0 - 1000A	E	
	(07) = 0 - 2000A	E	

ORDERING INFORMATION

Example:
150V, 100A Input with Split-Core Sensor and 0-±5Vdc Output Proportional to 0-15000Watts

PC8-003-01X5S

All units require 85-135Vac instrument power, 50-400Hz. Optional 230Vac instrument power - add suffix "-22"
Full-scale power (Watts) can be determined by the product of full-scale input voltage and full-scale input current.

OPTIONAL SPLIT-CORE CURRENT SENSOR AVAILABLE WITH UNITS OF 100 AMPS OR GREATER - ADD SUFFIX "S".

ADDITIONAL CURRENT RANGES AVAILABLE. CONSULT FACTORY.

SPECIFICATIONS

INPUT

Voltage .... See Tables
Current .... See Tables
Frequency Range .... dc to 400Hz
Power Factor .... Any
Response (Transient 90%) 50μs
Burden
Voltage .... Models under 50V .... >100kΩ
Models over 50V .... >1MΩ
Overload
Voltage .... 2 X F.S. or 600Vac/850Vdc max.
Current .... Using internal sensor .... 2 X F.S.
Using sensors C, D, E .... 50 X F.S.

DIELECTRIC TEST

Input/Output/Case 1000Vdc
Surge .... Withstands IEEE SWC test

OUTPUT

Loading
"B" models .... (0-±1mAdc output) 0-10kΩ
"E", "EM" models ... (4-20, 4-12-20mAdc output) ... 0-500Ω
"X5", "D" models .... (0-±5, 0-±10Vdc output) .... ≥2kΩ
Response Time .... (to 90%) .... <500ms
Field Adjustable Cal. .... ±10%

ACCURACY .... ±1.0%F.S.
Includes combined effects of voltage, current, load and power factor
Output Ripple .... <1.0% F.S.@60Hz

INSTRUMENT POWER

Standard 85-135Vac, 50-400Hz, 10VA
"-22" Option .... 230Vac, 50/60Hz, ±15%

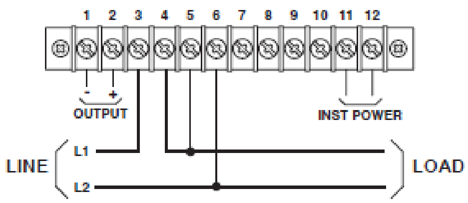
TEMPERATURE

Temperature Range .... 0ºC to 40ºC
Temperature Effect .... ±1.0% of Rdg, ±0.1% F.S. Output

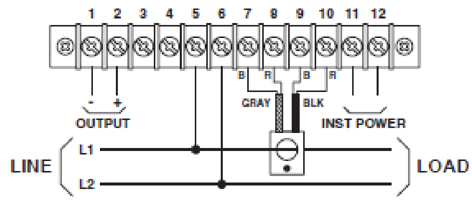
OHIO SEMITRONICS, INC. 4242 REYNOLDS DRIVE * HILLIARD, OHIO * 43026-1264
PHONE: (614) 777-1005 * FAX: (614) 777-4511
WWW.OHIOSEMITRONICS.COM * 1-800-537-6732

CONNECTIONS & CASE DIMENSIONS — MODEL PC8-

SINGLE-PHASE, VARIABLE-FREQUENCY (ONE-ELEMENT)

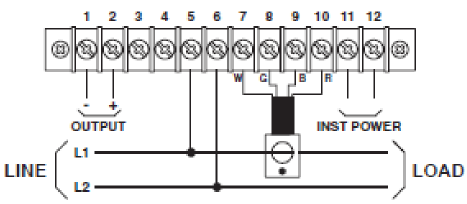


DIRECT-CONNECTION USING INTERNAL SENSOR



CONNECTION USING EXTERNAL SENSOR
WITH TWO CABLES.

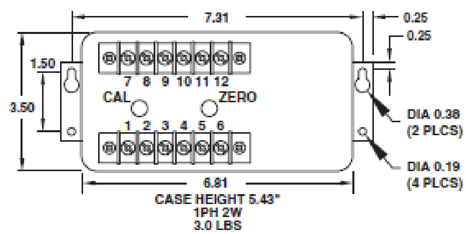
SENSOR CABLE SHIELD SHOULD BE CUT OFF.



CONNECTION USING EXTERNAL SENSOR
WITH ONE CABLE.

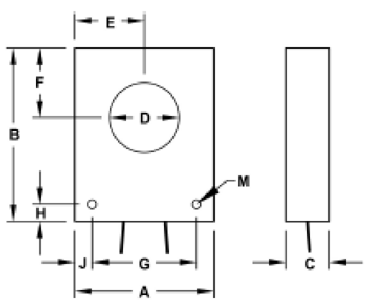
Warning! Shock Hazard!
Current Sensor Terminals are at Line Potential.

CASE DIMENSIONS



All dimensions in inches

SENSOR DIMENSIONS



SENSOR SIZE	SENSOR DIMENSIONS										WT. LBS.
	A	B	C	D	E	F	G	H	J	M	
C	2	2	3/4	3/4	1	7/8	1 1/2	1/4	1/4	5/32	0.28
D	3 1/8	4	3/4	1 1/8	1 9/16	1 1/2	2 1/8	1/2	1/2	11/64	0.75
E	4 1/8	5	1 1/4	2	2 1/16	2	3 1/4	7/16	7/16	17/64	2.80

All dimensions in inches

Solid-core models are supplied with 18-inch cables on sensor sizes C & D. All other solid-core models supplied with detachable 8-foot cable. Sensor size C split-core models are supplied with 8-foot attached cable. All other split-core models are supplied with detachable 8-foot cable. Longer cables are available.

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APPENDIX E: TIOCOAT™ SPECIFICATIONS SHEET

TIOCOAT

The coolest roof ever.

PRODUCT DESCRIPTION

DuROCK TIOCOAT is a bright white, polyurethane modified acrylic elastomeric coating. It is developed for use over existing roofing systems such as single-ply, modified bitumen, built-up (BUR) and concrete for commercial and industrial applications. DuROCK TIOCOAT forms a protective barrier that expands and contracts with varying temperatures. DuROCK TIOCOAT forms a weather resistant membrane that reflects the sun's heat which reduces the interior temperature of buildings. The dirt pick-up resistance technology of the acrylic polymer enhances the reflective properties of the membrane. DuROCK TIOCOAT is an easy to apply roof coating that offers years of durable protection.

BENEFITS OF ELASTOMERIC ROOF COATINGS

There are many benefits to using DuROCK TIOCOAT Elastomeric Roof Coating. The product applies to a smooth, clean and uniform appearance. It protects the roofing from UV degradation but most importantly it has high reflectivity for energy savings. DuROCK TIOCOAT also has high adhesion to existing asphaltic roof coatings.

APPLICATION

Before application ensure surface is clean and free of debris, dirt, mildew, chalk and degraded roofing membrane. The surface must be dry and free of all moisture. Do not thin product. Do not apply when temperatures are below 7ºC (45ºF). Do not apply when coating will be subjected to rain or heavy dew before it has had enough time to dry. Temperature and humidity conditions will affect drying time.

DuROCK TIOCOAT Elastomeric Roof Coating can be applied by brush, roller or spray gun (confirm sprayer gun and tip size with DuROCK representative). Apply coating uniformly ensuring entire surface is coated. Wait 6-8 hours before applying second coat.

DuROCK TIOCOAT Elastomeric Roof Coating is available in 19L (5 gallon) pails. The weight per pail is 24kg (53lb) covering approximately 400ft2 at a dry film thickness of 10 mil. DuROCK TIOCOAT Elastomeric Roof Coating is also available in totes. The weight per tote is 1200kg (2645lbs) covering approximately 20 000ft2 at a 10mil dry film thickness (in a one coat application).

For the complete specification please consult your DuROCK representative.

Physical Properties	Film Properties
Physical State: Viscous liquid Colour: White Density: 1.31g/mL Solids by Weight: 63±1% Solar Reflectivity: 89% Emissivity: 0.90	*Mechanical Properties, 75°F (24°C), initial* Tensile Strength, max, PSI: 284 Elongation @ break: 173.5%
	Mechanical Properties, 0°F (-18°), initial Tensile Strength, max, PSI: 1129 Elongation @ break: 46.2%
	Low Temperature Flexibility, -26°C, 1.27cm Mandrel: Pass
	Tear Resistance, kN/m: 22.6
	Accelerated Weathering, 1000hrs Xenon Arc Weatherometer: Pass
	Permeance, ng/(Pa.s.m2), Face down: 394.7
	Tack Free Time, minutes: 60

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Another Green Product By

DuROCK

APPENDIX E: BENJAMIN MOORE ALUMINUM PAINT SPECIFATIONS SHEET

Benjamin Moore®

WEATHERPROOF ALUMINUM PAINT 164

Features

- Possesses outstanding hiding and leafing properties
- Can be applied to large areas without brush or lap marks
- Excellent resistance to moisture, weather, and industrial fumes
- One coat covers most surfaces; two coats provide greater durability and longer wear
- Produces a beautiful, metallic finish of exceptional brilliance and great durability

General Description

Benjamin Moore® Weatherproof Aluminum Paint (164) produces a beautiful, metallic pigmented finish of exceptional brilliance and great durability. It has excellent hiding and spreads easily, while it protects metal and wood surfaces with a weatherproof film.

Recommended For

Residential or commercial applications where a premium quality finish is desired. For new and previously painted exterior or interior wood, metal, and cured masonry surfaces that are not subject to abrasion. Can withstand up to 600ºF temperature over suitable substrates requiring no primer.

Limitations

- Do not apply when air and surface temperatures are below 50°F (10°C)
- Aluminum pigment may rub off; should not be used on surfaces that are subject to frequent contact.

Product Information

Colors — Standard:
Aluminum

— Tint Bases:
Not available

— Special Colors:
Not Available

Certification:

VOC compliant in all regulated areas

Technical Assistance:
Available through your local authorized independent Benjamin Moore retailer. For the location of the retailer nearest you, call 1-800-826-2623, see www.benjaminmoore.com, or consult your local Yellow Pages.

Technical Data◊		Brilliant Metallic
Vehicle Type		Linseed Coumarone Indene
Pigment Type		Aluminum
Volume Solids		43%
Coverage per Gallon at Recommended Film Thickness		650 – 700 Sq. Ft.
Recommended Film Thickness	– Wet – Dry	2.4 mils 1.0 mils
Depending on surface texture and porosity. Be sure to estimate the right amount of paint for the job. This will ensure color uniformity and minimize the disposal of excess paint.		
Dry Time @ 77°F (25°C) @ 50% RH	– To Touch – To Recoat	3 Hours Overnight
Painted surfaces can be washed after two weeks. High humidity and cool temperatures will result in longer dry, recoat and service times.		
Dries By		Oxidation
Viscosity		< 50 KU
Flash Point		Flammable
Gloss / Sheen		Metallic
Surface Temperature at Application	– Min. – Max.	50°F 90°F
Thin With		Do Not Thin
Clean Up Thinner		Mineral Spirits
Weight Per Gallon		7.79 lbs
Storage Temperature	– Min. – Max.	40°F 90°F
Volatile Organic Compounds (VOC)		
436 Grams/Liter		3.64 Lbs./Gallon

◊ Reported values are for Aluminum. Contact Benjamin for values of other bases or colors

Benjamin Moore & Co., 101 Paragon Drive, Montvale, NJ 07645 Tel: (201) 573-9600 Fax: (201) 573-9046 www.benjaminmoore.com M72 164 US 112911

Surface Preparation

Surfaces to be painted should be clean, dry, and free from oil, grease, and dirt. Clean bare metal with mineral spirits or Benjamin Moore® Oil & Grease Emulsifier (P83) to remove contaminants. Remove all loose rust and scale from rusted metal with scraper and wire brush, or by sandblasting.

WARNING! If you scrape, sand or remove old paint, you may release lead dust. **LEAD IS TOXIC. EXPOSURE TO LEAD DUST CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE.** Wear a NIOSH-approved respirator to control lead exposure. Carefully clean up with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead.

Primer/Finish Systems

New surfaces should be fully primed, and previously painted surfaces may be primed or spot primed as necessary. For best hiding results, tint the primer to the approximate shade of the finish coat, especially when a significant color change is desired. **Special Note**: Certain custom colors require a Deep Color Base Primer tinted to a special prescription formula to achieve the desired color. Consult your retailer.

Wood:
Finish: 1 or 2 coats Benjamin Moore® Weatherproof Aluminum Paint (164)

Masonry, New and Unpainted (Including Unglazed Brick): Poured and precast concrete must be allowed to cure for 30 days; block construction should be allowed to cure for 30 days. All surfaces must be thoroughly prepared by removing the laitance and all loose particles.
Primer: Super Spec® Masonry Interior/Exterior 100% Acrylic Masonry Sealer (N/066)
Finish: 1 or 2 coats Benjamin Moore® Weatherproof Aluminum Paint (164)

Ferrous Metal (Steel and Iron): All ferrous metal surfaces must be wiped with mineral spirits or cleaned with Benjamin Moore® Oil & Grease Emulsifier (P83) to remove contaminants. Solvent and rags should be changed frequently.
Finish: 1 or 2 coats Benjamin Moore® Weatherproof Aluminum Paint (164)

Non-Ferrous Metal (Galvanized & Aluminum): All new metal surfaces must be thoroughly cleaned with Super Spec HP® Oil & Grease Emulsifier (P83) to remove contaminants. Solvent and rags should be changed frequently. New shiny non-ferrous metal surfaces that will be subject to abrasion should be dulled with very fine sandpaper or a synthetic steel wool pad to promote adhesion
Primer: Super Spec HP® Acrylic Metal Primer (P04)
Finish: 1 or 2 coats Benjamin Moore® Weatherproof Aluminum Paint (164)

Repaint, All Substrates: Prime bare areas with the primer recommended for the substrate above.

Application

Stir contents of can until mixture is smooth and uniform. Stir occasionally during use, enough to keep the metallic flakes in suspension. Apply one or two coats. For best results, use a Benjamin Moore® custom blended nylon/polyester or china bristle brush, Benjamin Moore® roller, or a similar product. This product can also be sprayed. A full, flowing coat produces the best results.

Do not thin. Do not paint when temperature of air is below 50°F (10°C), nor on damp or rainy days.

Spray, Airless: Fluid Pressure—1,500 to 2,000 PSI***
Tip—.013. Orifice
*** The overspray from aluminum paints will drift for long distances. Use the lowest pressure that provides satisfactory atomization. Do not spray this coating in windy conditions.

Thinning/Cleanup

Do not thin.

Clean brushes and equipment with mineral spirits.

USE COMPLETELY OR DISPOSE OF PROPERLY. This product contains organic solvents which may cause adverse effects to the environment if handled improperly. Save unused product for touch up purposes or a household hazardous waste collection program. Dry, empty containers may be recycled in a can recycling program. **Local disposal requirements vary; consult your sanitation department or state designated environmental agency on disposal options.**

DANGER - RAGS, STEEL WOOL OR WASTE SOAKED WITH THIS PRODUCT MAY SPONTANEOUSLY CATCH FIRE IF IMPROPERLY DISCARDED. IMMEDIATELY AFTER USE. PLASE RAGS, STEEL WOOD OR WASTE IN A SEALED WATER-FILLED METAL CONTAINER.

Environmental, Health & Safety Information

DANGER!

FLAMMABLE LIQUID AND VAPOR. VAPOR HARMFUL

Contains: Petroleum Distillates, Stoddard Solvent

HARMFUL OR FATAL IF SWALLOWED. ASPIRATION HAZARD. CAUSES IRRITATION TO EYES, SKIN AND RESPIRATORY TRACT

NOTICE: Repeated or prolonged exposure to organic solvents may lead to permanent brain and nervous system damage. Intentional misuse by deliberately concentrating and inhaling vapors may be harmful or fatal.

Keep away from heat and flame. Use only with adequate ventilation. Vapors are heavier than air and may travel along ground or may be moved by ventilation and ignited by pilot lights, or other flames, sparks, heaters, or static discharge. Do not breathe vapors, spray mist or sanding dust. Avoid contact with eyes and prolonged or repeated contact with skin. To avoid breathing vapors or spray mist open windows and doors or use other means to ensure fresh air entry during application and drying. If you experience eye watering, headache or dizziness or if air monitoring demonstrates vapor levels are above the applicable limits, wear an appropriate, properly fitted respirator (NIOSH approved) during and after application. Follow respirator manufacturer's directions for respirator use. Aspiration Hazard. Small amounts aspirated into the respiratory system may cause mild to severe pulmonary injury. Close container after each use.

WARNING: This product contains a chemical known to the state of California to cause cancer and birth defects, or other reproductive harm.

FIRST AID: If affected by inhalation of vapors or spray mist, remove to fresh air. In case of eye contact, immediately flush with plenty of water for at least 15 minutes and get medical attention immediately; for skin, wash thoroughly with soap and water. If swallowed, do not induce vomiting. Get medical attention immediately.

IN CASE OF FIRE – Use foam, CO_2, dry chemical or water fog. **SPILL –** Absorb with inert material and dispose of as specified under **"Thinning/CleanUp".**

KEEP OUT OF REACH OF CHILDREN
KEEP FROM FREEZING

Refer to Material Safety Data Sheet for additional health and safety information.

VITA

Steven Anthony Sciara was born in Akron, Ohio. In 1983, he earned a Bachelor of Arts degree in Psychology at the University of South Florida, married and moved to Alcoa, Tennessee where he worked in retail. In 1990, he was transferred to Missouri by his employer where he and his wife had two children, Aubrey and Tanner. In 1997, Mr. Sciara and his family relocated to Boone, North Carolina, resigned from the retail management field, and acquired a position as a Construction Project Manager while also starting S A Sciara Design. In 2006, he accepted a position as Project Coordinator at a design studio in Foscoe, North Carolina. Mr. Sciara earned a Bachelor of Science degree summa cum laude in Interior Design at Appalachian State University in 2010. He sought a Master of Science degree in Technology with a dual concentration in Appropriate Technology and Building Science, graduating December 2012. He presented a paper in May, 2012 at the World Renewable Energy Forum in Denver, Colorado, co-authored by Dr. Brian Raichle.

With travel to Canada, United States (lower 48), Alaska, Puerto Rico, Honduras, Peru and Brazil, Mr. Sciara has volunteered his experience to benefit others, and explore construction and technological opportunities in many geographic locations.

Honors and Affiliations:

- Epsilon Pi Tau Honor Society, Appalachian State University, 2011-2012
- U.S. Department of Energy Solar Decathlon International Competition, 2010-2011 Sponsorship Coordinator, Appalachian State University 2010-2011 (solardecathlon.gov)
- U.S. Department of Energy Solar Decathlon International Competition, 2010 Design Team, Appalachian State University
- Appalachian State University College of Business Pitch Your Idea in 90 Seconds-Second Place winner, 2010
- Eta Sigma Honor Society, Appalachian State University
- Interior Design Ambassador, Appalachian State University, 2008
- American Society of Interior Designers, Student Representative to the Board ASID Carolinas, 2009-2010
- American Society of Interior Designers, Student Member 2008-2011